# A MANUAL
# FOR THE MAINTAINANCE AND MODIFICATION
# OF THE HARDWARE AND SOFTWARE
# OF THE CORROSION EROSION TESTER CONTROL SYSTEM

by

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## Section 0.1 Introduction

The control system for the PMRL CanMet Corrosion Erosion Test Facility is comprised of an IBM PC microcomputer with a custom electronic interface, various transducers for sensing or affecting parameters of the rig's operation, and software which monitors, displays and controls those parameters interactively. This manual is intended to be used as a detailed guide for the maintenance and/or modification of any component, hardware or software, of this control system. For Test Facility operating procedures refer to the CES High Temperature Corrosion Erosion Test Facility Instruction Manual.

Taken as a whole the mechanical and electrical components of the Corrosion Erosion Test Facility may seem complex and confusing. If the subcomponents are examined singly, though, it is not difficult to understand how each one works. This divide and conquer' principle applies equally to understanding the control system software. This manual will therefore begin with a brief overview, then jump right into detailed descriptions of subsystems. These will be presented from a hardware point of view in section one followed by a software perspective in section two.

## Section 0.2 System Overview

The purpose of the High Temperature Corrosion Erosion Test Facility is to subject small samples of a material to torturous, but precisely controlled, conditions. These conditions may include temperatures in excess of 1000 degrees C and erosion by high velocity, particle laden streams of corrosive gas. The purpose of this manual is to describe the systems which measure and control these conditions.

Samples of material to be tested are placed in holders on a rotatable disc located in the main furnace, a large 12" i.d. split ( clam shell') electric furnace. Two shafts enter the main furnace through water-cooled bearings. Both shafts are on the main vertical axis through the centre of the furnace. The shaft entering the top of the furnace supports the sample disc, while that entering the bottom rotates the particle stream chopper associated with the particle velocity measurement system.

Mounted above the main furnace, and on an axis

parallel to, but displaced several inches from the main axis of the furnace, are (from the top) the GE gas heater, the particle entrainment venturi, and the acceleration furnace.

On its upper surface, equally spaced around the sample disc are four adjustable holders for samples, an instrumented calibration sample, and a hole. The disc can be rotated, under computer control, to bring each of the six positions under the stream of erodant.

The erodant gas stream is comprised of up to three components: The main carrier gas flow enters the G.E. gas heater at the top of the apparatus. The particle laden flow from the Sylco powder feeder and the optional $SO_2$ enter below the gas heater. The combined gas and particle stream then pass through a meter long tube heated by an electric tube furnace, the acceleration furnace. Here the particles attain terminal velocity, while the gas temperature is maintained or slightly increased.

The exact measurement and control of such a system is an intricate problem. One must know, and be able to control, the exact temperature, velocity, density and composition of the gas, the size, temperature, and velocity of the eroding particles, as well as the temperature and treatment time of the sample. Any chemical or physical changes which may occur can only complicate the problem further.

Precise control of all the inputs to an experiment should allow one at least to repeat it exactly. To measure the exact conditions in the heart of an experiment is another matter. The corrosion erosion test facility is designed to do the former, and to a lesser extent, the latter. The apparatus can control exactly the gas and particle flow rates, the heat inputs, and the time of experiment. These, together with such parameters as barometric pressure, particle and sample composition, gas nozzle diameter, impact angle etc., more or less determine the outcome of the experiment; i.e. the exact nature of the erosion which occurs. To compare experimental conditions obtained in the apparatus with those found elsewhere, i.e. other experimenter's apparatus or the environment of a practical problem, one must attempt to measure or predict, as accurately as possible, the actual values of the above parameters which pertain at the sample.

Given known values of gas flow rate, composition, thermal input, and nozzle diameter the gas velocity and temperature rise can, theoretically be predicted.

Dimensional changes due to thermal expansion, or erosion of the apparatus over time, as well as the complexity of the fluidynamic regime near the jet orifice, (where the erodant stream enters the sample furnace) are among factors which contribute to the uncertainty of any such predictions. The corrosion erosion test facility provides for both prediction and measurement of these parameters in real time.

The prediction of gas velocity and temperature rise is based on principles to be found in any thermodynamics or physical chemistry text.[1] The rise in temperature of a gas for a given input of thermal energy is computed by dividing the energy, in appropriate units, by the specific heat of the gas. Since the apparatus is not pressurized, we use $C_p$ the specific heat for constant pressure. Unfortunately, $C_p$ is a function of temperature and for the large temperature changes involved, it may not be approximated by a constant. Polynomials which accurately predict the $C_p$s for a variety of gases over wide temperature ranges have been published. These, and a simple iterative algorithm, are used by the test facility's control program to predict the temperature rise of any gas mixture composed of nitrogen, oxygen, carbon dioxide, carbon monoxide, water vapour, or sulfur dioxide, in any ratios. Given the computed temperature, the volumetric thermal expansion of the gas is computed from the Gas Law, PV = NRT, and the gas velocity is calculated from the volume flow rate divided by the area of the nozzle orifice.

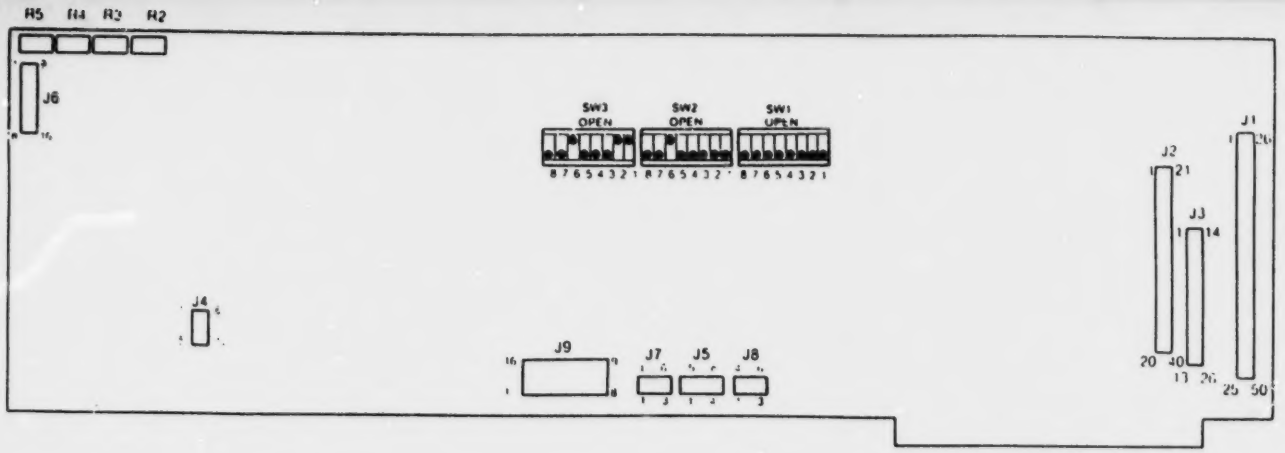
The Corrosion Erosion Test Facility also provides for direct measurement of gas temperature and particle velocity. A special test sample, with an embedded thermocouple, may be rotated under the erodant stream. By adjusting the energy input to the gas stream until no change in the temperature measured by this thermocouple is noted on moving the test sample in or out of the gas stream, one may justifiably make the assumption that the gas is at the same temperature as the test sample.

Particle velocity may be measured by a number of means, however the requirements of on line measurement in a hostile environment limit the methods which may be used. The most accurate suitable method would probably

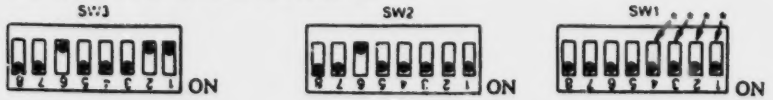
---

1 e.g. Physical Chemistry, 4th edition, Farrington Daniels and Robert A. Alberty. John Wiley & Sons, New York

See chapters one and nine.

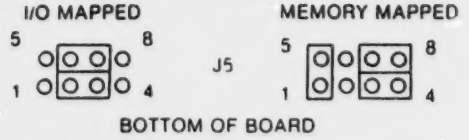



The switch configuration for setting the starting address of this board at I/O location 0710 Hex will look like:




*These are not specified since they are only used in memory mapped mode.

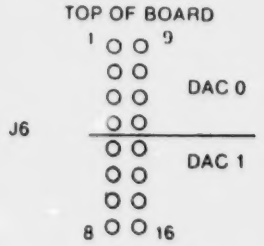
**J5:** Jumper J5, located at the bottom of the board, controls the I/O mapped vs memory mapped option as follows:



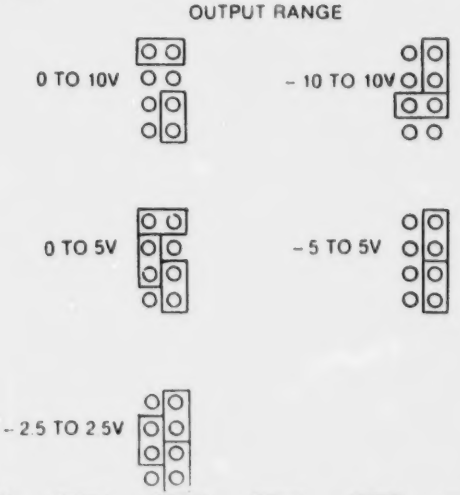

Place the jumpers over the pins as indicated.

**figure 1**

**J6:** Jumper J6, located at the top left of the board, controls the output range for the D/A's. Eight pins correspond to each DAC.




To jumper a DAC for a specific output range, place jumpers on the pins shown below:



be laser doppler interferometry, though it would have doubled the cost and trebled the complexity of the apparatus to incorporate this instrumentation. The method chosen was a simple time-of-flight scheme, in which a chopper gates the particle stream a known distance upstream of a special acoustic sensor which detects the impact of the particles when they arrive.

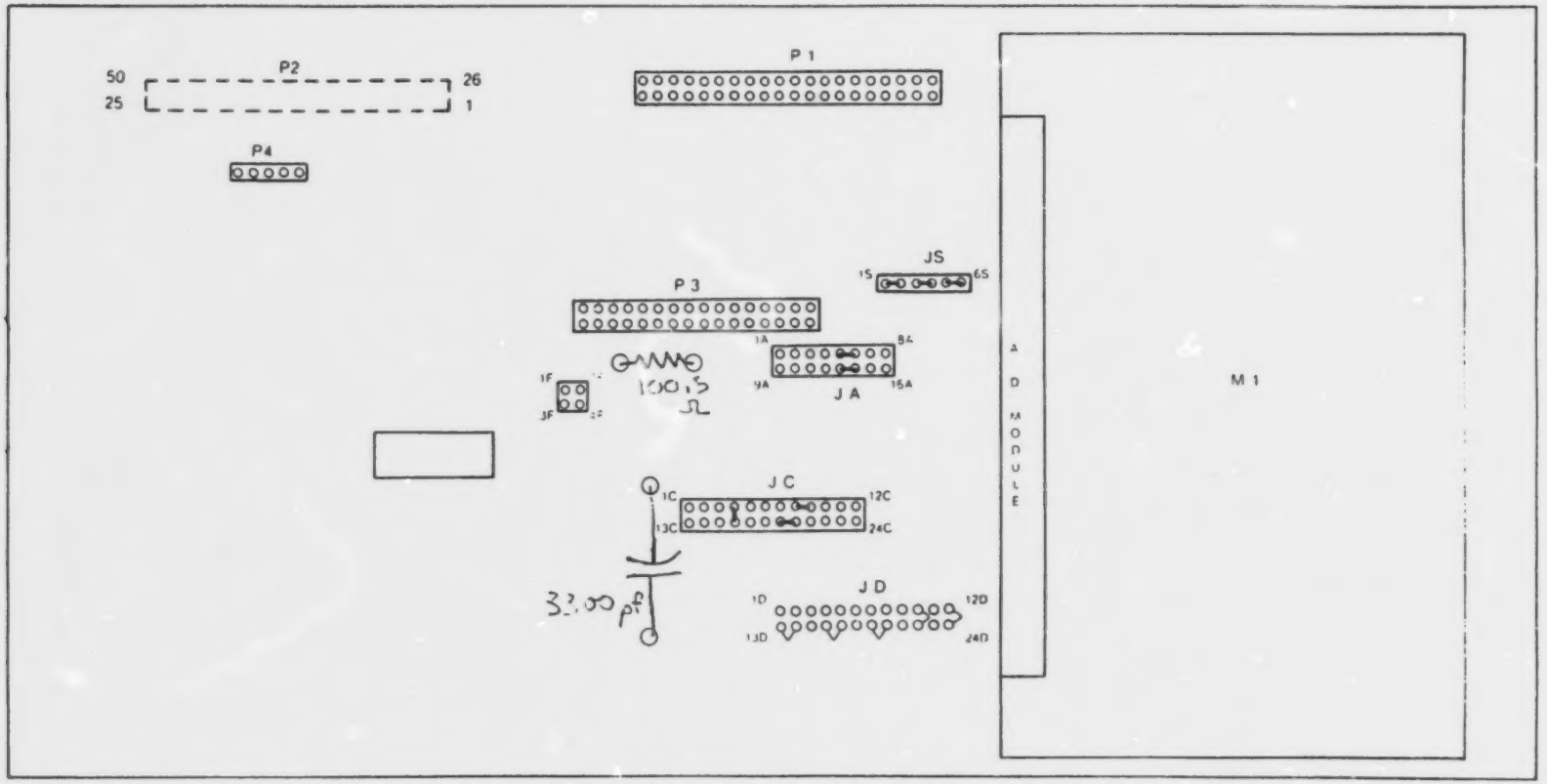

P2
50
25
26
1
P4
P1
P3
JS
1S
6S
1A
8A
9A
15A
JA
1F
3F
100Ω
JC
1C
12C
13C
24C
33.00 pf
JD
1D
12D
13D
24D
A D MODULE
M 1

**figure 2**

# Part 1: Hardware

## Section 1.1: The Tecmar Lab Master i/o interface

All sense and control information received or sent by the corrosion erosion facility's control program goes through a Tecmar Lab Master interface. The Lab Master board for the IBM Personal Computer is a versatile, general purpose interface intended for industrial and scientific applications requiring precision analog-to-digital and digital-to-analog conversions. The installation manual supplied with the board contains about ninety pages of technical information, documenting all its possible configurations and programmable modes. Much of this section is adapted from that document. However, here we will describe only those modes and the configuration used in the operation of the corrosion erosion test facility.

The Lab Master consists of a mother board which plugs into a slot in the IBM PC bus, and a daughter board which connects to it by a short ( 4' ) ribbon cable. All the analog to digital conversions are done on the daughter board. The model selected for use in the corrosion erosion facility has sixteen 12 bit analog-to-digital input channels, two 12 bit digital-to-analog outputs. In addition an 8255 parallel port chip provides up to 24 digital (on/off) inputs and/or outputs, and an AMD 9513 timer chip provides five 16 bit programmable timers.

### 1.1.1 Board Configuration

There are switch settings, jumpers, and patches on both the mother and daughter boards which must be correctly set to use the Lab Master for a particular purpose. The digital-to-analog configuration pins and switches associated with bus addressing and memory or i/o mapping reside on the mother board, inside the PC chassis. The daughter board contains all the analog-to-digital conversion circuitry and associated configuration pins.

mother -board

On the mother board are three dual-inline type switch units, each having eight small switches, designed to be operated with a pencil tip. These set the address at which the first of the board's programmable registers may be accessed. The Lab Master occupies 16 consecutive addresses in either the I/O

address space or the memory address space of the IBM PC. A set of jumpers marked J5 near the bottom of the board determine whether I/O or memory mapping is used. The factory settings are for I/O mapped at address 0710 hex, and are unchanged for the corrosion erosion test facility. See figure 2 for details of the switches and jumpers.

DACs

The digital-to-analog converters (DACs) can be configured as 0 to 10V, 0 to 5V, -10 to 10V, -5 to 5V, or -2.5 to 2.5V. The configuration is set by the pattern of jumpers at J6 near the top of the Lab Master motherboard. These DACs are used to control the gas valves, and the speed controller for the particle stream chopper motor. A pertinent fact here is that when the computer is reset, the DAC outputs return to their initial values. For the bipolar ranges, e.g. -5 to 5V, this is zero volts. For the unipolar ranges, however, this is the midpoint of the range: e.g. On reset a DAC configured for the 0 to 10V range will be set to 5.0 volts. Obviously it is desirous that any machinery controlled by a DAC should be reset to a safe (usually OFF ) state if the control computer is reset, e.g. by a power interruption. For this and other reasons both DACs are set for the -5 to 5V range. See figure 1 for details of DAC range configuration.

daughter board

The daughter board's analog-to-digital circuitry is configured for 16 single ended, bipolar, 12 bit channels with a hardware programmed gain of 200, giving a full scale range of -50mv to +50mv. To alter a new Tecmar Lab Master daughter board from the factory settings to this configuration requires the placement of several shorting pins, and soldering one capacitor and a precision resistor. See figure 2 for placement of the shorting pins, resistor and capacitor. The capacitor should be a low loss type of 3300pf. The resistor should be 100.5 ohms exactly. On the original corrosion erosion test facility board, this was achieved by trimming' a larger value with parallel resistors until the correct value was measured, using a precision six place digital voltmeter. The addition of the capacitor slows the maximum conversion rate to 12 KHz, but is necessary to allow settling of the instrumentation amplifier.

### 1.1.2 Analog output: The DACs

There are two 12 bit digital-to-analog converters on the motherboard, DAC0 and DAC1 . The outputs of these go to a ten pin connector at J4. DAC0 output is

on pin 1, DAC1 output is on pin 2, all others are ground.

Since the PC bus is only eight bits wide, it is not possible to send a twelve bit binary number in one step, therefore each DAC has two registers associated with it, one for the least significant (low) eight bits, and one for the most significant (high) four bits. One should always write the high register first, then the low byte. This is important because the DAC output will change only when the low byte is written. In this way one can be sure that the output is updated only when all the bits have be set correctly. Note that you must always write to the low byte, even if only the high byte has been altered.

The addresses of the DAC registers are tabulated below:

| | |
|---|---|
| 710 hex | low byte of DAC0 |
| 711 hex | high four bits of DAC0 |
| 712 hex | low byte of DAC1 |
| 713 hex | high four bits of DAC1 |

Note that the in the bytes sent to adresses 711 and 713 the upper four bits of the byte are ignored, i.e. the high 4 bits of DAC0 are the lowest 4 bits of the byte sent to address 711.

two's complement

As mentioned in section 1.1.1 above, the DACs are configured for -5 to 5 volt operation. Numbers should be formatted as 12 bit twos complement numbers. To form a twos complement negative number, take the complement of a binary number (change all 1s to 0s and 0s to 1s) and add 1. Positive numbers are straight binary. This gives 212 = 4096 levels between -5 and 5 volts, giving a resolution of 10V/4096 = 2.4 mV .

### 1.1.3 Analog Input: The daughter board

A fifty pin connector J1, at the far right of the motherboard connects, via ribbon cable, to the daughter board. This cable carries digital data, multiplexer addresses, and control signals between the mother board in the PC chassis and the daughter board, located inside a large steel electrical box on one end of the corrosion erosion tester's frame. When reassembling the system it is <u>imperative</u> that this cable be connected correctly i.e. pin 1 on the motherboard to pin 1 on the daughter board, or damage may result. On the daughter board this cable connects to the bottom (solder side), with pin one at the end furthest from the corner. All

cable

analog signals are confined to the daughter board.

input voltages

The 40 pin ribbon connector at P1D on the daughter board is where input voltages enter. The pins are as follows:

| PIN | CHANNEL |
|---|---|
| 20 | 0 |
| 19 | 8 |
| 18 | 1 |
| 17 | 9 |
| 16 | 2 |
| 15 | 10 |
| 14 | 3 |
| 13 | 11 |
| 12 | 4 |
| 11 | 12 |
| 10 | 5 |
| 9 | 13 |
| 8 | 6 |
| 7 | 14 |
| 6 | 7 |
| 5 | 15 |
| 1-4,21-40 | gnd |

modes

The Lab Master may be operated in several modes for analog data acquisition, programmable by jumpers and/or software. The corrosion erosion tester control system, however, has only simple requirements in this regard. In particular there is no requirement for high speed analog data input, in part because furnace temperatures, and the like, change in minutes or perhaps seconds, but never mili- or micro- seconds. This means that there is no need for the auto-increment feature of the analog multiplexer or for interrupts to be generated on completion of an analog-to-digital conversion. The auto-increment feature and interrupts are enabled or disabled by writing to the control and status register of the Lab Master board at location 714 hex.

A one written to bit 7 of this location disables autoincrement mode. Bits 6,5,4,3 enable interrupts on A-to-D converting, A-to_D overrun, timer output, and the parallel port, respectively. Bit 2 enables external triggering of A-to-D conversion. Bits 0 and 1 are used with software programmed gain, an option not available with the model of Lab Master used in the corrosion erosion tester. The control software simply writes 128 dec (80 hex) to the control register, disabling

read a voltage

To read an analog voltage from one of the sixteen multiplexed inputs one must select the desired channel, tell the Lab Master to start a conversion, wait for it to finish, then read the digital value. The channel number is first written to address 715 hex, then conversion is started by writing anything to address 716 hex. Bit 7 of the control and status register at 714 hex changes from a 0 to a 1 when the conversion is complete. Reading the high byte of data resets it to 0. The converted data is read at addresses 715 hex (low byte) and 716 hex (high bits).
For example, to read the voltage on input channel five using BASIC one could enter:

```
 5   OUT &H715,5: REM channel number
10   OUT &H716,0: REM start convert
15   WAIT &H714,128: REM wait for bit 7 of status to
change
20   LBYTE = INP(&H715): HBYTE = INP(&H716): REM read
data
25   LBYTE = LBYTE AND 255: HBYTE = HBYTE AND 255: REM
bit mask
30   MV = (HBYTE*256 + LBYTE)*50/4096: REM convert to
millivolts
40   PRINT "channel 5 is ";MV;" millivolts"
```

### 1.1.4 Special functions: The Am9513 timer

Several features of the corrosion erosion test facility's control system make use of the Am9513 System Timing Controller on the Lab Master interface. These are the particle stream chopper RPM measurement, the Silco powder feeder feed screw RPM, the particle time-of-flight measurement (for particle velocity), and the 220 volt triac control (pulse width modulation) for the G.E. gas heater.

The Am9513 is a single LSI device which accomplishes all the above measurement and control functions, without putting any demands on the CPU. By this I mean that none of the above functions generate interrupts, or need to be serviced by the CPU at all, except when a new reading is required or an output must be changed. This is fortunate because in the programming language chosen for this project, BASIC, interrupt service routines cannot easily be implemented and would require that hard-to-maintain machine language routines be linked in. All of these functions are accomplished by appropriate use of the Am9513's versatile programmable timers. The device has five timers and an oscillator with frequency scaled outputs.

The Am9513 is a highly programmable device and can be configured to do almost anything that might conceivably be done with combinations of timers, counters, gates, and an oscillator. Please refer to the manufacturer's data sheet or Appendix A of the Tecmar Lab Master Installation Manual for complete details of the Am9513's capabilities and programming.

The Am9513 timer signals are on connector J2 of the motherboard, which also carries Done' and External start conversion' signals for the ADC:

| PIN | In/Out | SIGNAL NAME |
|---|---|---|
| | ADC signals | |
| 16 | output | done conversion |
| 3 | input | External start conversion |
| | 9513 Timer signals | |
| 4 | output | out 5 |
| 9 | input | gate 5 |
| 14 | input | source 5 |
| 5 | output | out 4 |
| 10 | input | gate 4 |
| 15 | input | source 4 |
| 6 | output | out 3 |
| 11 | input | gate 3 |
| 17 | input | source 3 |
| 7 | output | out 2 |
| 12 | input | gate 2 |
| 18 | input | source 2 |
| 8 | output | out 1 |
| 13 | input | gate 1 |
| 19 | input | source 1 |
| 20 | output | F1 oscillator output (1 MHz) |
| 1,2 | | +5v |
| 21-40 | | ground |

RPM measurement

For RPM measurement, an Am9513 timer is configured as a retriggerable one-shot: In this mode an external trigger saves the current value of the counter (in the Hold register) and restarts the count. For example, the feed-screw RPM measurement uses timer 2 with the count input from the F2 oscillator output, and high edge triggering on pin 12 of connector J2. The F2 clock is derived from the master oscillator, F1, which runs at 1 MHz, and is equal to F1/16 = 62500 Hz. In operation, this mode means that the control program need only read

the Hold register at any time to get the time interval count between the most recent two triggers. For the time-of-flight measurement timer 4 is set up similarly but with an active high level gate, which counts only while pin 10 of J2 is held high. For the triac control, timer 5 is used as a programmable monostable: An input trigger, derived from the 60Hz mains, loads the counter from a programmable register; when the count reaches zero, an output pulse triggers the triac.

time of flight

triac control

### 1.1.5 Digital I/O: The 8255

The 8255A parallel port chip has 24 I/O lines all of which connect to a ribbon connector on the edge of the Lab Master motherboard. The following is a brief summary of the functions of this chip. For greater detail refer to the Intel 8255A specification sheet, or appendix B of the Tecmar Lab Master Installation Manual.

The 8255's 24 I/O lines are organized into three groups of eight, called ports A, B, and C. These are programmed through four registers at adresses 071C hex through 071F hex:

| | |
|---|---|
| 071C | data register for parallel port A |
| 071D | data register for parallel port B |
| 071E | data register for parallel port C |
| 071F | 8255 control register |

The 8255's I/O lines connect to a 26 pin ribbon connector at J3 on the mother board. The pin assignments for this connector are tabulated below:

| Pin | Signal Name |
|---|---|
| 1 | PA7 |
| 14 | PA6 |
| 2 | PA5 |
| 15 | PA4 |
| 3 | PA3 |
| 16 | PA2 |
| 4 | PA1 |
| 17 | PA0 |
| 5 | PC7 |
| 18 | PC6 |
| 6 | PC5 |
| 19 | PC4 |

| | |
|---|---|
| 7 | PC3 |
| 20 | PC2 |
| 8 | PC1 |
| 21 | PC0 |
| | |
| 9 | PB7 |
| 22 | PB6 |
| 10 | PB5 |
| 23 | PB4 |
| 11 | PB3 |
| 24 | PB2 |
| 12 | PB1 |
| 25 | PB0 |
| | |
| 13,26 | GROUND |

modes

There are three possible modes of operation of the 8255: Mode 0, basic i/o mode; mode 1, strobed i/o; and mode 2, bidirectional bus mode. The corrosion erosion facility software uses only mode 0, with port A programmed as an input port and ports B and C as output ports. To set the 8255 to this state the software sends 90 hex (144 dec) to the 8255's control port at 71F hex. In BASIC this could be written as:

```
OUT &H71F,&H90
```

write port

To read port A or write ports B or C, the OUT and INP functions are used: e.g To write the bit pattern 10001001 (89 hex) to port B, turning on lines PB7, PB3 and PB0, one could use the BASIC statement:

```
OUT &H71D,&H89
```

read port

Similarly, to read the bit pattern of signals on port A, one could use the statement:

```
PRINT INP(&H71C)
```

## 1.2 The Transducer interface circuits

The circuits described in this section can be considered extensions of the Lab Master interface: Each is designed either to condition an external signal for input through the Lab Master, or to amplify an output control signal from it.

### 1.2.1 Physical Organization: PCBs and cables

In addition to the two Tecmar boards, there are three etched printed circuit boards carrying various circuits that comprise the sensor and control interface electronics. These are all located in the right side of the main electrical box mounted to the corrosion erosion tester's aluminum frame. In the left side of the box or mounted to its left exterior are the high power triac and optically isolated solid state relays which allow low voltage control of the 220v power delivered to the gas heater and furnace elements. Transducers and some active components are also located at other points in the apparatus.

The largest printed circuit board carries a hodge-podge of circuits for triac control (gas heater circuit), sample and hold (gas valve control), analog input scaling and compensation, (gas flow sensors and thermocouples), and various transistors, gates, and invertors for buffering signals. The safety shutoff circuit described in 1.2.2 is also on this board.

particle velocity board

Two smaller etched boards are specialized signal conditioning modules: One board, containing a high gain amplifier, a filter and several gates, conditions the signal from the acoustic particle impact detector, and integrates it with the shaft tachometer pulse to deliver a time-of-flight dependant pulse width to the computer. The other board performs scaling and true rms conversion of signals from current and voltage sensing transformers, measuring power input to the GE gas heater.

gas heat power board

high voltages

The boards contain only low voltages, with exception of a small, isolated area in the upper portion of the large pcb, which carries 220 volts, at low current. A small perforated board also located in the main electrical box, which carries some components involved in the trigger circuit for the gas heater triac also connects directly to the 220 v supply. The 220 volt mains may be shut off independat of power to

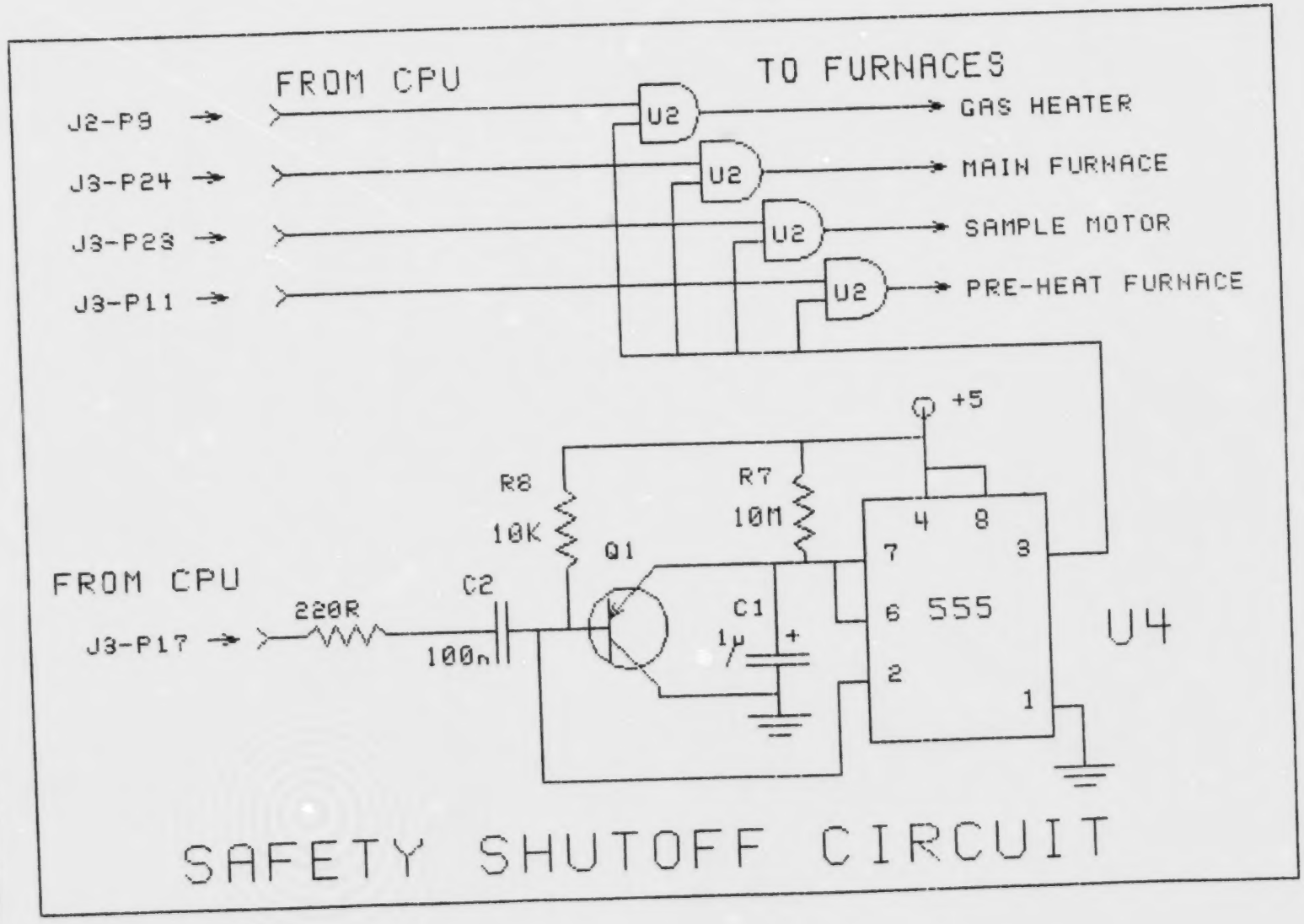

FROM CPU
TO FURNACES
J2-P9
J3-P24
J3-P23
J3-P11
U2
U2
U2
U2
GAS HEATER
MAIN FURNACE
SAMPLE MOTOR
PRE-HEAT FURNACE
+5
R8
10K
R7
10M
Q1
FROM CPU
J3-P17
220R
C2
100n
C1
1µ
+
4
8
7
3
6
555
2
1
U4
SAFETY SHUTOFF CIRCUIT

**figure 3**

the computer or interface electronics, for safety during diagnosis or repair.

cables

As described in section 1.1.3, above, a fifty pin cable connects J1 on the Lab Master's motherboard with P2D on the daughter board. It is imperative that this cable be oriented correctly. In addition, several cables connect the large interface board with both of the Lab Master boards: A single 50 wire ribbon has been split into a 40 and a 10 wire cable. These connect to J2 and J4 on the Lab Master mother board respectivly, and carry the timer and DAC output signals to a single 50 pin connector at JB1 on the large interface board. A 26 wire ribbon also connnects J3 on the motherboard to JB3 on the large interface board. A 40 wire ribbon connects the Lab Master daughterboard's 16 analog inputs at P1D to the large interface board at JB4. One last 16 wire ribbon cable connects JB2 on the large interface board to the particle impact signal conditioning board. This carries power to the smaller board and conducts timing signals through to JB1 and the AM9513 timer on the Lab Master motherboard.

A number of single wire connections also enter the large interface board, including analog inputs I and V from the gas heater power input measurement board, gas flow meter analog inputs, thermocouples, control signal outputs for furnace relays, high voltage triac trigger pulses, analog output for gas valves, chopper motor variable speed control, etc. These wires are all equipped with insulated gold plated inline connectors for easy servicing.

### 1.2.2 Safety Shutoff Circuit

The safety shutoff circuit is a simple edge sensitive retriggerable monostable, designed around a 555 timer IC. (See figure 3). Its purpose is to prevent damage to the heat generating components of the test facility, in the event of a failure of the control computer or software, such as might be caused by a brownout or temporary interruption of power. The monostable has a time constant of approximately ten seconds, and is triggered by a software generated pulse which occurs at a rate somewhat faster than .1 Hz. Thus a steady, all's well ' output level is available when the software is operating correctly. This output enables the main and acceleration tube furnaces, the gas heater, and the forward direction sample disc advance controls, through four and gates at U2. Any form of hardware or software crash' should therefore

result in shutdown of these circuits within ten seconds.

Although this circuit is a useful and necessary part of the control system interface, it can be a nuisance during diagnostic procedures. It can make it difficult to distinguish between various possible causes of a malfunction. For certain procedures, i.e. when it is desired to test the functionality of the interface circuitry, independant of the computer

disabling

software, it may be useful to disable this circuit. A simple way to accomplish this is to remove the 555 from its socket, and jumper pins 3 and eight together. This will result in a continuous high level to the AND gates enabling the gas heater, furnaces, and sample motor. **WARNING: Never do this with the 220 volt supply connected and the gas heater in place. The gas heater may be easily destroyed in fractions of a second if power is applied in excess of the maximum allowed for the gas flow rate through it at any instant. The software normally monitors this and will shutoff the power in time (usually) to prevent failure.**

### 1.2.3 Thermocouples

Three type K thermocouples are used to measure the temperatures of the main and pre-heat (acceleration tube) furnaces and the calibration sample block. A brief review of thermocouple physics and technology follows:

theory

The thermoelectric effect occurs when a junction is formed between dissimilar metals. For a complete discussion of the physics of thermoelectricity refer to a text on semiconductor physics or materials science.[2] One feature of thermocouple physics is most important to us: Thermocouples measure only temperature differences, not absolute temperature. This can be seen as a consequence of the Second Law of Thermodynamics: If a circuit, all parts of which have equal temperature, can generate a voltage, then energy would have to be created, violating the Second Law. In fact the rule is that the sum of the voltages around any closed loop of thermocouples, all at the same temperature, is zero. Thermocouples can be formed wherever two dissimilar metals meet: Thus extension wires and connectors should be composed of matching

---

2 e.g. Introduction to Properties of Materials 2nd Edition, by Daniel Rosenthal and Robert M. Asimow, Van Nostrand Reinhold Co., New York.

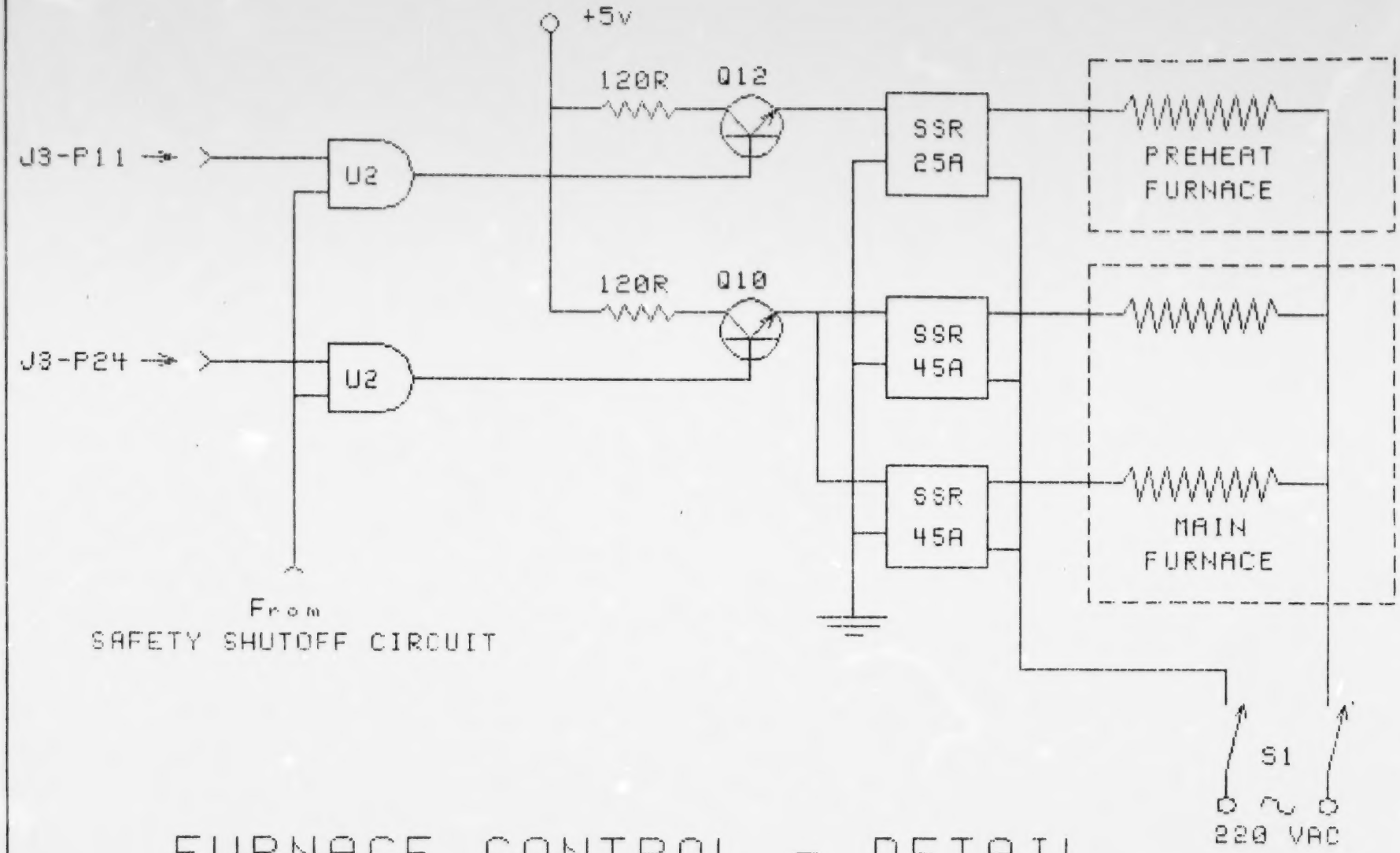
materials for accurate results. This may be neglected only for portions of the circuit for which there can be no appreciable temperature difference: It is permissible, for example, to solder low temperature junctions. This is because, if the entire tip can be considered at one temperature, the above rule implies that any intermediate junction potentials, due to solder, will cancel out, the overall effect being the same as if joint were welded.

Absolute temperature may be measured using two thermocouples to measure the difference between a known temperature and an unknown one. A standard laboratory method uses two thermocouples in series with a microvoltmeter. One thermocouple is placed in a distilled water-ice bath, the other in the unknown environment. Tables such as are found in the CRC Handbook or the Omega Temperature Measurement Handbook are then used to determine the temperature difference between the unknown temperature and 0 degrees Celsius. In a variation of this method, the known' temperature is measured by an alternate means, e.g. a thermistor, and this value is converted to an equivalent thermocouple reading and added to the indication of the millivoltmeter before converting to temperature. (This method is equivalent to simply adding room temperature to the table reading, only if the thermocouple has a perfectly linear response - few do).

iso-thermal block

The latter method is used in the Corrosion Erosion Facility: All the thermocouples terminate at a single terminal block mounted to the inside wall of a heavy gauge steel electrical box. This constitutes an isothermal block' insofar as all the junctions between dissimilar metals, except the measurement thermocouples, are held at the same temperature. Also mounted in a small hole in this block is an Analog Devices AD590 integrated temperature sensing IC. This unit produces a linear current response to absolute temperature; approximately 1 microamp per degree Kelvin. A trimmable resistor of approximately 100 ohms converts this current to a voltage, giving 27.3 mv at zero Celsius (273 Kelvin).

The AD590 output is connected to the Lab Master's analog input channel number fifteen. The value read in from this channel is used to compensate the thermocouple readings, and also to display the room temperature' indication on the computer display. Resolution is about 0.1 degree Celsius.




FURNACE CONTROL - DETAIL

**figure 4**

### 1.2.4 Furnace Control

The power input to the furnaces is controlled by switching the power on and off in a preportional pulse manner with a cycle of about ten seconds. Refering to figure 4,two signals from the computer, enabled by AND gates, buffered by transistors Q12 and Q10 control one 25A and two 45A solid state relays. The 25A relay controls the smaller acceleration tube or pre-heat furnace. The two 45A relays control the two elements of the large clam shell' main furnace.

Diagnosis of this circuit is hampered by the fact that it requires an enabling signal from the safety shutoff circuit to function. This confuses the assignment of blame' should a furnace refuse to heat up. See section 1.2.2 for details of disabling the safety shutoff circuit.

### 1.2.5 Matheson Gas Flow Meters

The Matheson gas flow meters are a heated-tube type mass flow sensor with self contained electronic conditioning. Output range is from 0 to 5 volts, linear with mass flow. There are three flow meters with measurement ranges of 0 - 50 litres per minute, 0 to .5 lpm and 0 - 20 lpm respectively. See figure 5. The outputs are scaled by a factor of 100:1 to match them to the 50mv full scale range of the Lab Master daughter board analog inputs.

### 1.2.6 Gas Valve Control Circuit

As described in section 1.1.2, above, the Lab Master board has two 12 bit digital to analog outputs. One is used to control the speed of the particle stream interrupter (chopper) motor. There are two gas valves which are controlled by the computer, furthermore if complex gas mixtures must be used, it might be desirable to expand this number in the future. For these reasons some way of adding analog outputs is necessary. This is acomplished by multiplexing four output signals on DAC1, and demultiplexing them onto separate sample-and-hold circuits on the large interface board. The circuit which performs the demultiplexing, see figure 6, consists of an MC14529 dual one-to-four line analog multiplexer, and four identical circuits each comprised of a CMOS invertor, a capacitor and two transistors.

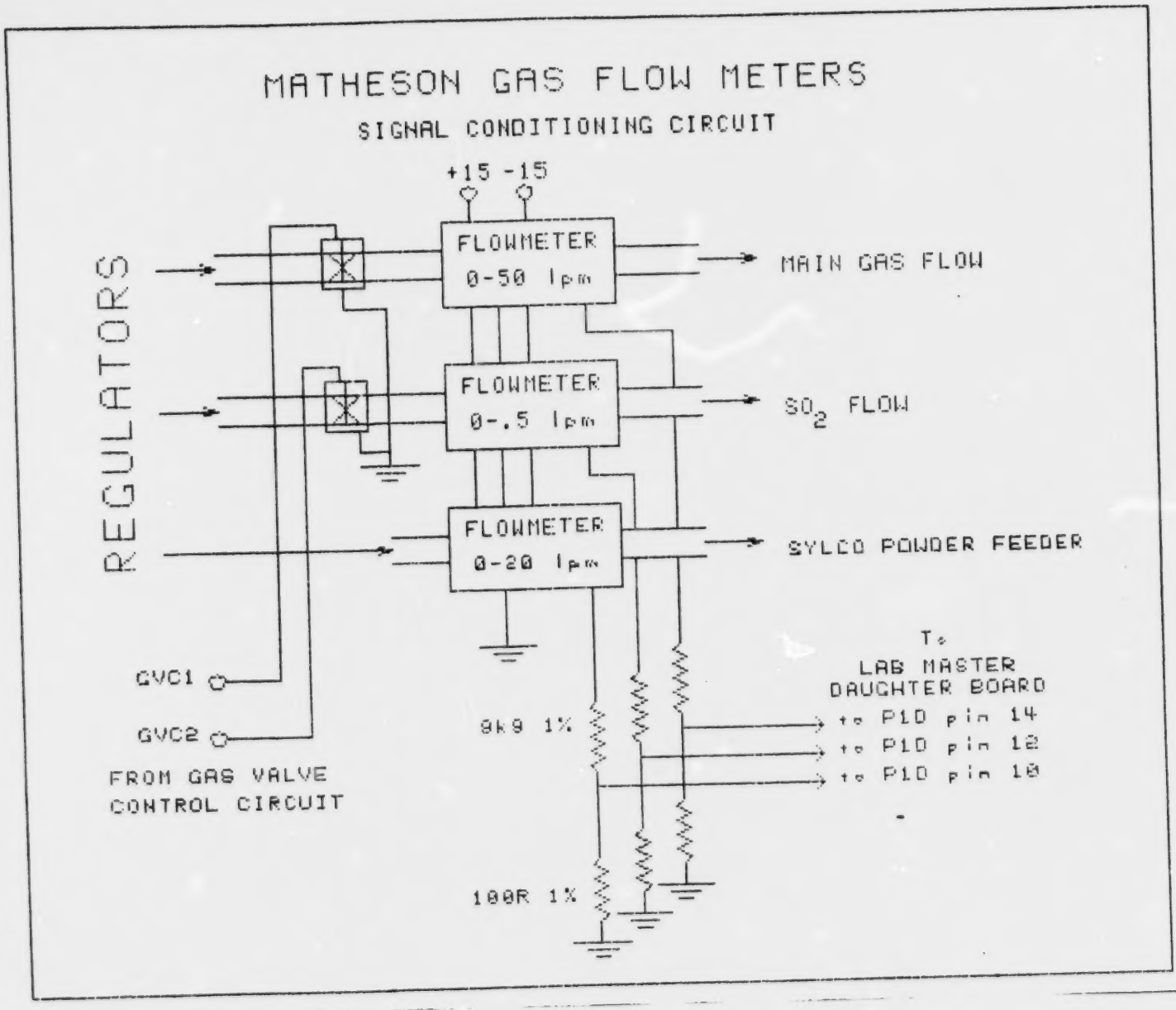

MATHESON GAS FLOW METERS
SIGNAL CONDITIONING CIRCUIT
+15 -15
REGULATORS
FLOWMETER
0-50 lpm
FLOWMETER
0-.5 lpm
FLOWMETER
0-20 lpm
MAIN GAS FLOW
$SO_2$ FLOW
SYLCO POWDER FEEDER
GVC1
GVC2
FROM GAS VALVE
CONTROL CIRCUIT
9k9 1%
100R 1%
To
LAB MASTER
DAUGHTER BOARD
to P10 pin 14
to P10 pin 12
to P10 pin 10

figure 5

The CMOS invertor and capacitor form an integrator, the transistors buffer the output. In operation, the MC4529 can be considered to be a four position, two gang, rotary switch controlled by the two bit binary number present on pins 6 and 7. When one of the four channels is selected, resistor R11 is connected across one of the capacitors, making that channel into an inverting amplifier with gain = R11/R12 = 1. Some damping occurs because the capacitor is still in the circuit, but essential output will follow input. When a different channel is selected, the capacitor will retain its charge, maintaining (for several seconds) the integrator's output voltage.

### 1.2.7 Screw feed RPM measurement

The RPM of the Sylco powder feeder's auger is measured and logged by the corrosion erosion tester software to ensure that the experimental record contains a reliable measure of the powder feed rate. The powder feeder has been modified, by the addition of a black and white plastic ring fitted to an exposed portion of the auger shaft, and an reflective infrared transmitter-receptor assembly (similar to bar code wand units). A high quality square-wave signal is generated when the varying reflectance of the rotating shaft is detected by the optical device and conditioned by a simple circuit, figure 7, consisting of three CMOS invertors: A simple low pass filter is followed by a schmidt trigger circuit with hysteresis.

This circuit is usually quite reliable, but problems may occur if the black and white ring becomes displaced, or smudged. Also, operating the unit with the powder feeder protective housing removed is not recommended, as external light sources, especially florescent, may affect the circuit.

### 1.2.8 Sample Positioning Motor

The shaft which supports the sample disc is rotated by a small reversible electric motor fitted with a sprocket and chain drive. A small brass disc near the top of the shaft has perforations which when aligned with an optical switch indicate correct positioning of the sample disc at one of six positions. The brass disc also serves as a cam for two limit switches which prevent over-rotation of the shaft: Over-rotation could destroy the thermocouple wires that thread down the shaft.

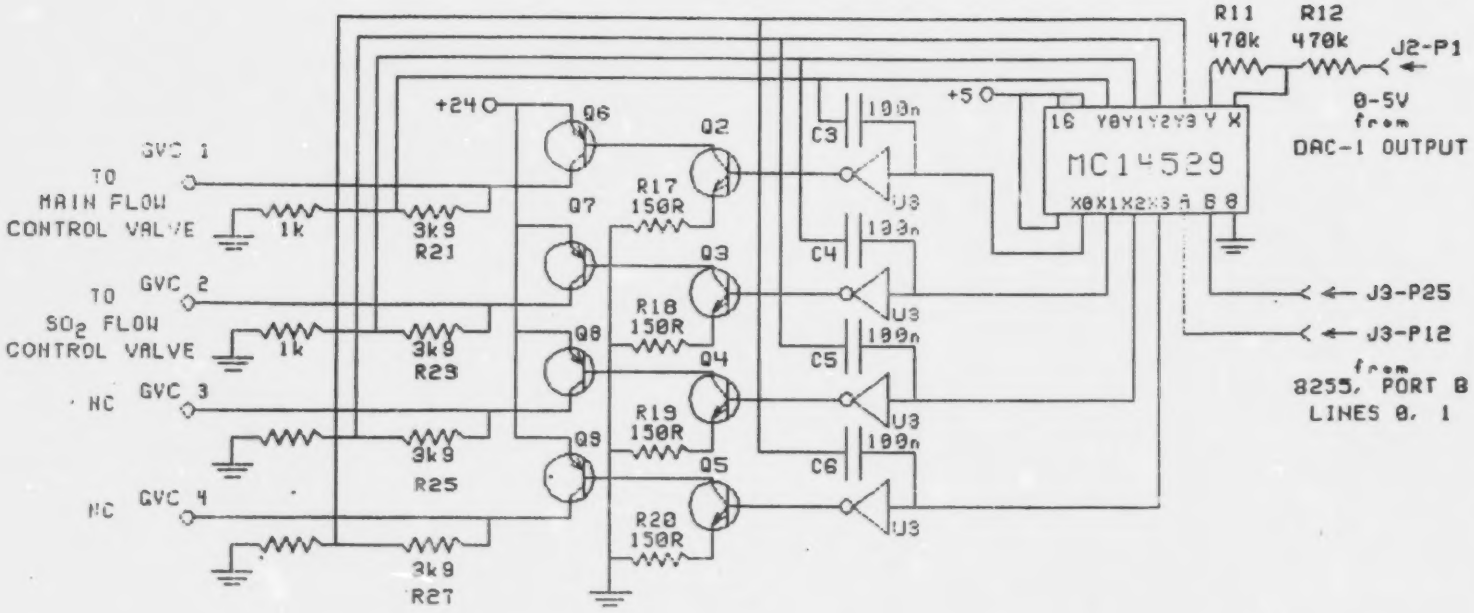

GVC 1
TO
MAIN FLOW
CONTROL VALVE
1k
3k9
R21
GVC 2
TO
$SO_2$ FLOW
CONTROL VALVE
1k
3k9
R23
NC
GVC 3
3k9
R25
NC
GVC 4
3k9
R27
+24
Q6
Q7
Q8
Q9
Q2
Q3
Q4
Q5
R17
150R
R18
150R
R19
150R
R20
150R
+5
C3
C4
C5
C6
100n
U3
MC14529
R11
470k
R12
470k
J2-P1
0-5V
from
DAC-1 OUTPUT
J3-P25
J3-P12
from
8255, PORT B
LINES 0, 1

figure 6

Optically isolated solid state relays control the forward and reverse motion of the motor. In operation the computer first reverses the motor for a pre-determined time to insure that the shaft is at the zero position. A limit switch prevents over-rotation. A desired position is thereafter found by advancing the shaft until the correct number of signals has been received from the optical switch. To prevent overshoot, the motor is caused to slow down as it approaches a hole, by pulsing the current rapidly on and off. Diagnosis of this circuit may be aided by disabling the safety shutoff circuit. See section 1.2.2 .

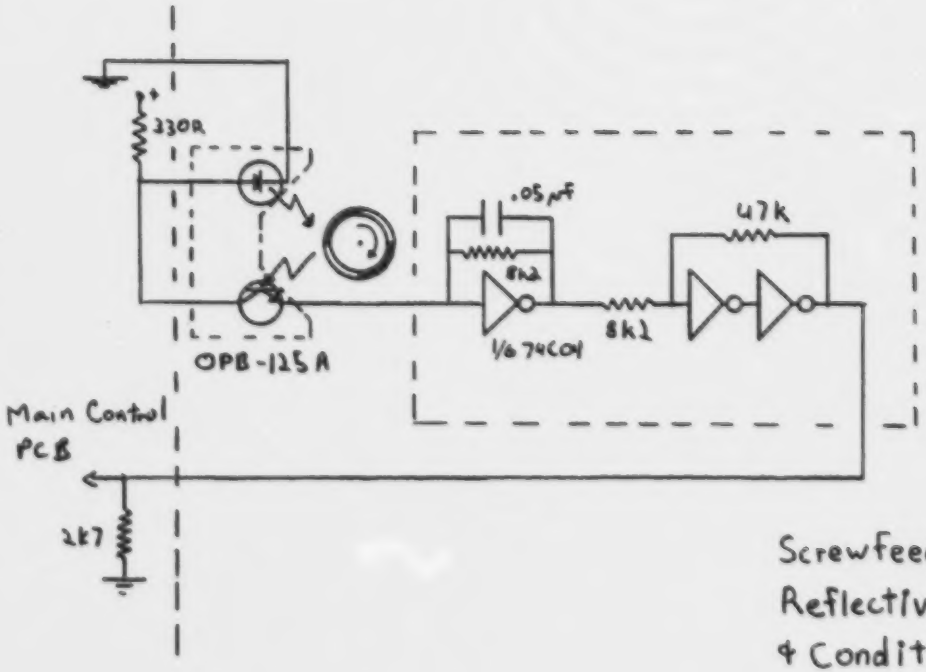
### 1.2.9 Chopper Speed Control

The particle stream chopper disc is supported by a water-cooled shaft that enters the main furnace from below. The shaft is rotated at speeds up to 1000 RPM by a timing belt driven by a variable speed DC motor. The motor and controller are manufactured by Ultracon. The Ultracon controller is mounted to an integral cast heat sink assembly, which has been mounted in the door of the main electrical box containing the other control system interface circuitry. See figure 11 for a diagram of the Ultracon control circuit. A zero to five volt signal from the Lab Master's DAC2 output controls the speed of the motor. An isolator module, also supplied by Ultracon, protects the computer from ground faults and high voltages. This is a small encapsulated block with four wires protruding from it, which is affixed to an inner wall of the electrical box by a self-adhesive backing.

Although the Ultracon controller sets the speed of the motor with some accuracy, The actual speed of the chopper shaft is directly measured by the computer, using an optical interrupter. This is partly a side benefit of the particle velocity measurement system.

### 1.2.10 Gas Heater Power Input Sense Circuit

The gas heater is controlled by a variable duty-cycle triac control circuit. Power dissipation is also a function of the heating element temperature though, since its resistance varies with temperature. Element temperature is in turn a strong function of gas flow rate. Indeed, restricting the flow at high power levels will certainly result in failure of the element by fusing. To simplify this complex situation, the corrosion erosion tester control system simply measures the actual power input to the gas heater directly.




Screwfeed RPM
Reflective Pickup
& Conditioning
Circuit.

figure 7

Figure 8, shows the circuit which outputs dc voltages corosponding to actual true RMS values of current and voltage through the gas heater. Power is equal to the product of these values, since the load is essentially a pure resistance. Gas heater current is sensed via two cascaded toroidal current transformers. The output of the second current transformer is amplified by a op-amp current mirror circuit, and a second op-amp AC gain stage. A small step-down isolation transformer and a trimmable potentiometer scale the voltage appropriately. True root mean square conversion is performed by a pair of Analog Devices AD536 RMS to DC convertor devices. The voltage and current are read in on the Lab Master analog input channels 6 and 7 respectively. The input value in milivolts is to be multiplied by 5.0 for channel 6, and by .25 for channel 7 to obtain volts and amps, respectively.

This circuit has some drift, and should be carefully calibrated for both offset and scale. As a final check the computed value, as displayed by the computer, should be checked against an accurate wattmeter.

### 1.1.11 Gas Heater Power Control

There are two distinct circuits associated with gas heater power control. The circuit of figure 9 (a) is simply a zero crossing detector which provides a clean logic edge for timing the triac firing pulse. This pulse goes to the gate input of timer #5 of the AM9513 programmable timer i.c. on the Lab Master motherboard. This timer is set up as a programmable-length mono-stable: A software selected time after receiving the zero-crossing edge, the timer output goes high. The timer output triggers firing of the gas heater triac via the circuit of figure 9 (b).

In figure 9 (b) the MOC3011 is a special device containg an optically triggered triac and an LED in a single 4 pin DIP. This provides isolation between the low voltage circuitry of the main control pcb and the 220 v.a.c. of the triac circuit. A second triac provides the current gain necessary to trigger the large 40 amp triac controlling the gas heater. Triggering is through a capacitative network to prevent overheating of the low power triac.

Corrosion-Erosion Test Rig

True RMS to D.C. conversion for Gas heater Power Input Sense.

G. Park 1984

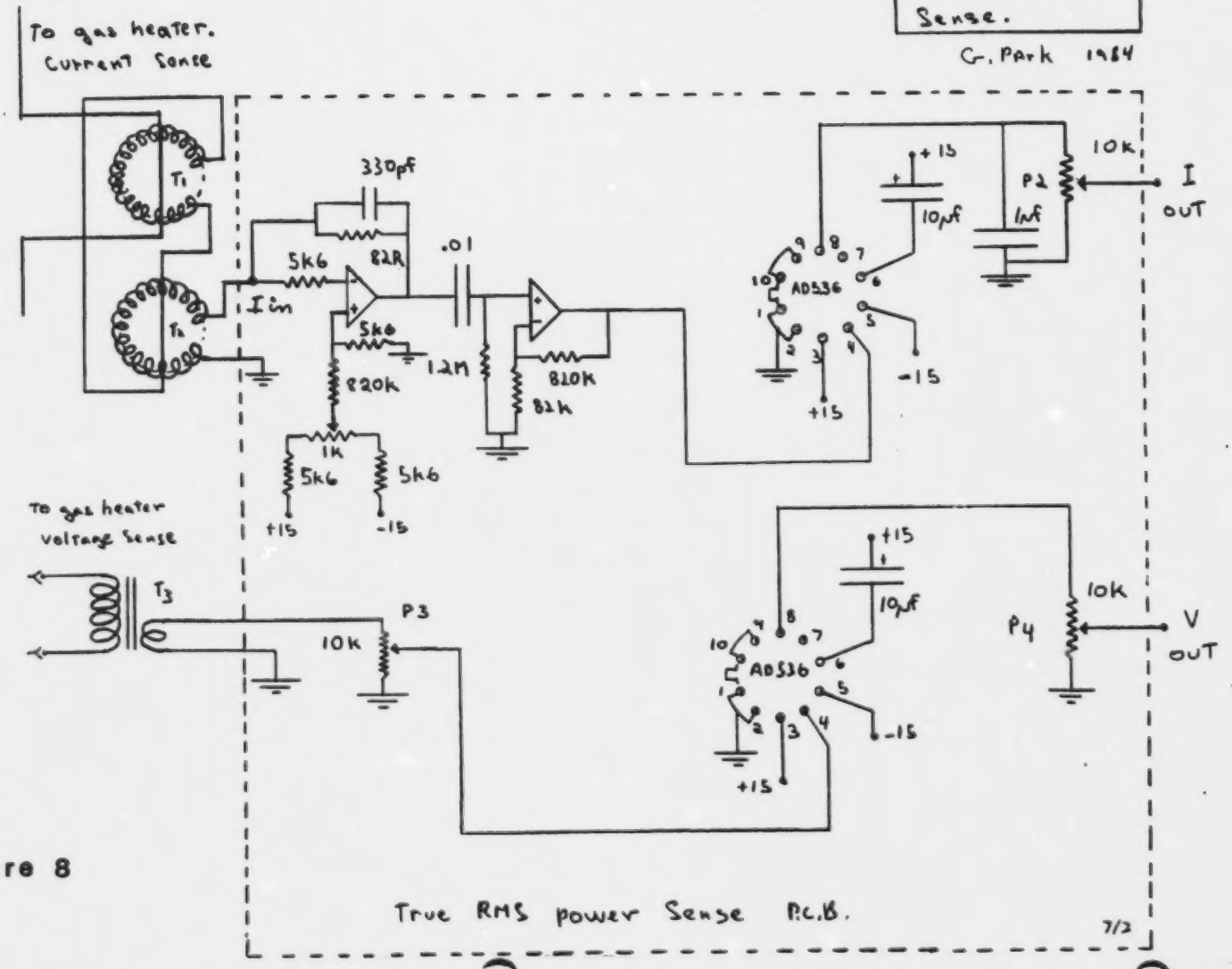



figure 8

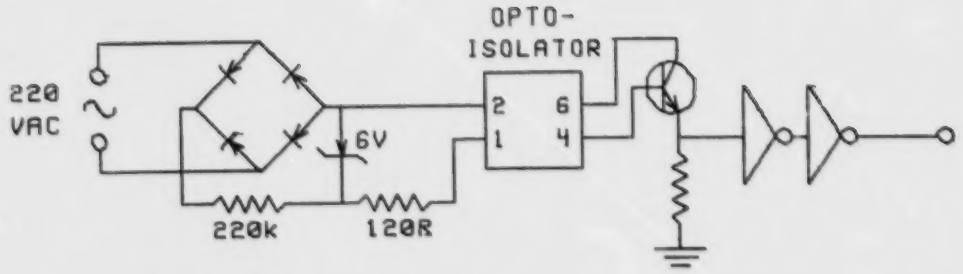
### 1.1.12 Particle velocity sensor signal conditioning

When the sample holder disc is positioned at position zero, the particle stream is allowed to pass through an open hole in the disc. Just below the sample holder disc the particle stream encounters a rotating chopper which periodically interrupts the stream. The rpm of the chopper is under software control. Outside the furnace, a brass disc with the same cutout pattern as the chopper is fixed to the chopper shaft with a ring and set screw. An optical switch generates a logic high level indicating when the chopper is open to the flow of particles. The set screw may be loosened to allow adjustment of the brass disc: With the furnace open and cold, manually rotate the chopper shaft until the indicator LED just comes on. The edge of the chopper should now just bisect the opening of the particle acceleration tube.

The chopped particle stream finally impacts a special machined ceramic target, fixed to the end of an alumina rod. The lower end of the rod, outside the furnace, is enclosed by a water cooled chamber and has a small piezo-electric transducer mounted to it. Signals from this sensor detect the impact of particles on the target, and, with the chopper open signal, allow time-of-flight measurements to estimate the particle stream velocity.

The circuit at the top of figure 10 amplifies and conmditions the impact sensor signal, cleans up the optical switch signal, and integrates the two to produces a clean gate pulse for the AM9513 timer.
The 1k trimmer adjusts the overall gain of the impact sensor amplifier stage. The 10k trimmer adjusts the comparator offset. These should be interactively adjusted so that the circuit can just detect a pinch of sand dropped on the ceramic target. Too much sensitivity will result in spurious indications due to vibrations, bearing rumble, etc., from the chopper and its motor.

The set-reset flip-flop is set by the opening of the chopper and reset when the first particle impact is detected. Software determines the median time of flight and estimates the particle stream's velocity.


OPTO-
ISOLATOR
220
VAC
6V
2
1
6
4
220k
120R

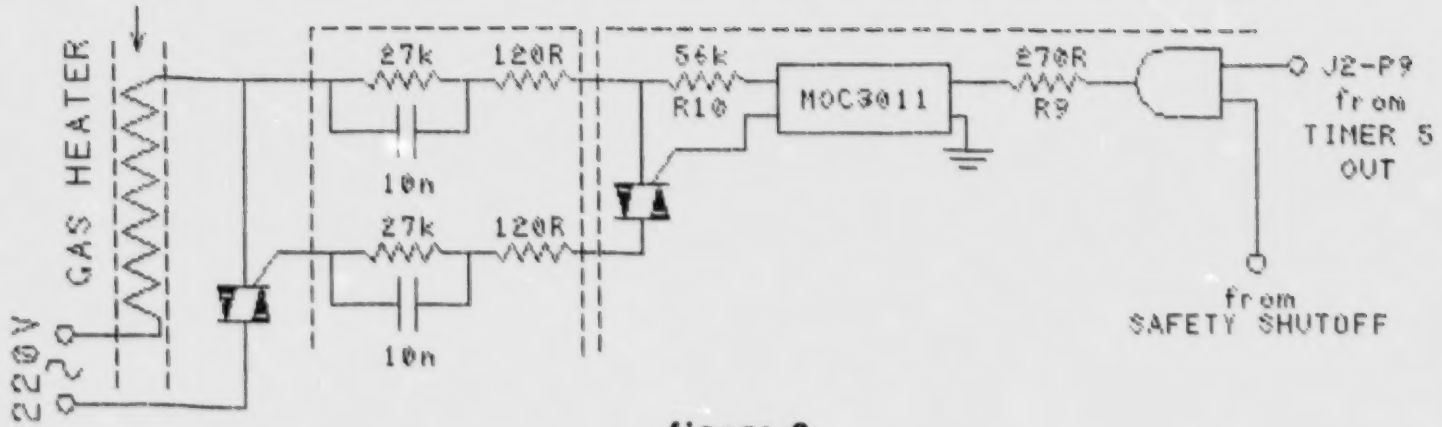

GAS HEATER
220V
27k
120R
10n
27k
120R
10n
56k
R10
MOC3011
270R
R9
J2-P9
from
TIMER 5
OUT
from
SAFETY SHUTOFF

**figure 9**

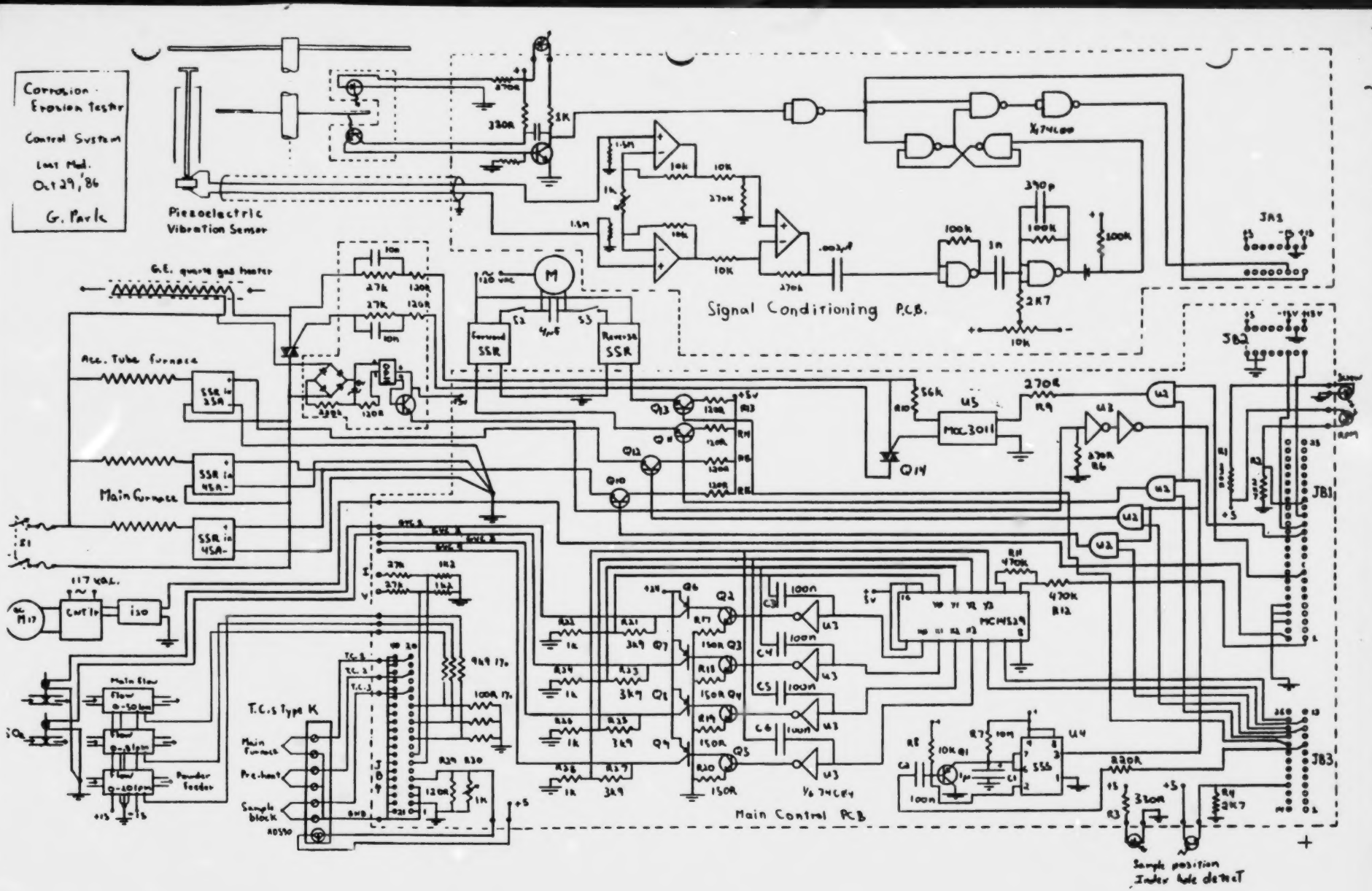
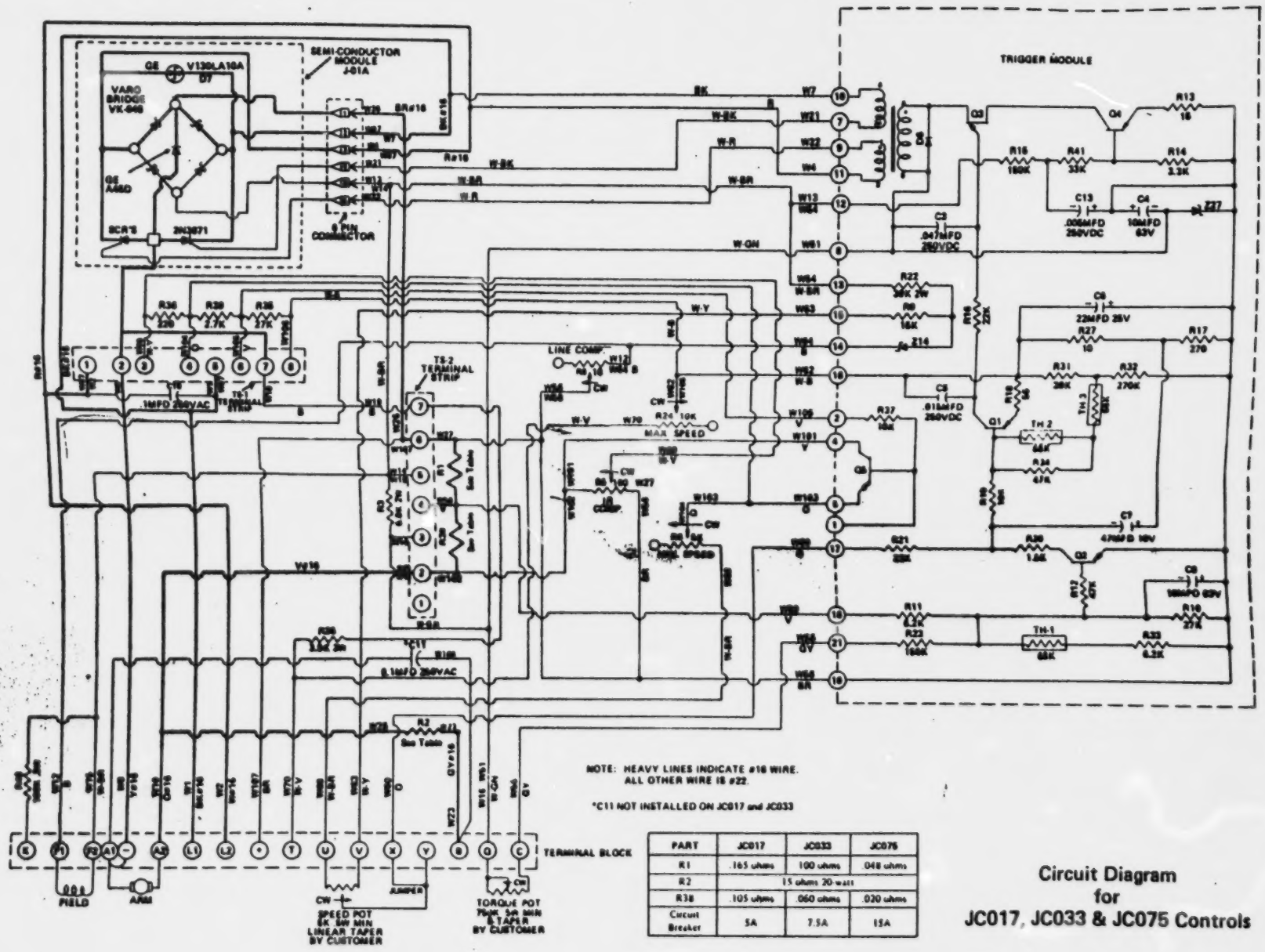

Corrosion - Erosion Tester
Control System
Last Mod.
Oct 29, '86
G. Park
Piezoelectric Vibration Sensor
Signal Conditioning P.C.B.
Main Control P.C.B.
Acc. Tube furnace
Main Furnace
Pre-heat
Sample block
T.C.s Type K
Powder feeder
Sample position Index hole detect
Forward SSR
Reverse SSR
MC1413P
MCM5229
555
1/6 74C04
1/4 74LS00

figure 10




| PART | JC017 | JC033 | JC075 |
|---|---|---|---|
| R1 | .165 ohms | .100 ohms | .048 ohms |
| R2 | 15 ohms 20-watt | | |
| R38 | .105 ohms | .060 ohms | .020 ohms |
| Circuit Breaker | 5A | 7.5A | 15A |

**Circuit Diagram for JC017, JC033 & JC075 Controls**

figure 11

# Part 2: Software

## 2.1 Control Program Overview

Large programs are usually built from smaller modules in a hierarchical manner, analogous to the modules, submodules, and components of a complex machine like an automobile or spacecraft. This organization is essential if a program or machine is to be understandable, repairable, and alterable. This section introduces the corrosion erosion test facility's software components.

The syntax of structured programming languages like Pascal, or C, enforce or encourage a modular, hierarchical design. The language used for the control program, Microsoft BASIC, is, unfortunately, not a very structured language. For this reason certain stylistic principles have been adopted to add structure and modularity to the program. In the following it will be assumed that the reader has some familiarity with BASIC language programming.

One of the main failings of BASIC is that all variables are global. This makes modular programming difficult: Ideally program modules should be written and tested separately, independant of the rest of the program. Each module should have its own variables, and communicate with the main program and other modules in a well defined way. When all variables are global, however, the module writer must choose his or her variable names carefully to avoid conflicts with other modules. This becomes increasingly difficult as the size of a program increases, especially if several authors must collaborate on a project. Global variabals also tend to make for ill-defined communications between modules: If any module can modify any variable, then it may become difficult to untangle a module's inputs from its outputs and its internal variables.

Another feature of BASIC which can be a problem for modular programming is line numbering and the GOTO statement. These, together, mean that not only can any module modify any variable, but any piece of code may transfer control to any other place in the program, without regard to any hierarchical structure.

### 2.1.1 Programming conventions

The stylistic principles which have been adopted for the control program are listed below. They are

designed to alleviate some of the above problems with BASIC programming. These represent guidelines only, but should be followed, wherever possible, by anyone modifying or augmenting the control program software.

i) GOTO should be used infrequently, if at all. Long jumps, inter-module jumps, and backward jumps should be especially avoided.

ii) Line numbering for each functional module should start fresh with a large whole number. This makes the program structure more visible and facilitates the insertion of additional code.

iii) Variable names used within a particular module should all begin with the same letter or letter pair.

iv) When calling a module, any input variables to that module should be set on the same line as, or the line above the GOSUB.

Adherence to these guidelines results in a BASIC program which is much more readable than it might otherwise be.

Viewing the control program in a hierarchical manner, there is a preamble section in which data is obtained from the operator, and variables and hardware are initialized, followed by a loop which calls subroutines to measure parameters, compute and output control signals and display current conditions. Some of the subroutines may call sub-subroutines and so on for several levels. Many of the lowest level routines are, however, shared by higher level routines: e.g. There is a single routine which reads a voltage on a given TecMar Labmaster channel; all the routines which require analog input call this routine.

### 2.1.2 Preamble: Initializing the system.

The preamble section of the control program is comprised of lines 1 through 990 inclusive. Lines 100 to 192 declare arrays, initialize constant variables and read in some parameters from a special file:

```
100 REM definitions
105 DIM GCOMP(6),CPGTOT(4),SDISCR$(10),CESHEAD$(3)
106 DIM MPTR(20),SPTR(20),BLANK(20),BLOK(50)
110 DEF FNHI(X)=INT(X/256)
120 DEF FNLO(X)=X-FNHI(X)*256
```

```
121 REM cp of gas mixture in j/l stp
122 DEF FNCP(T)=(CPGTOT(1)+CPGTOT(2)*T+CPGTOT(3)*T*T
                +CPGTOT(4)*T*T*T)/22.4
130 LINV=220*1.414:GHR=40:PI=3.14159:REM line voltage,
      gasheater resistance
135 NOZA=.0000367:REM nozzle area in m2
140 FF$=CHR$(12):LF$=CHR$(10):REM form feed and line
feed
150 OPEN "i",#1,"erode.def"
160 INPUT#1, NOZA:REM nozzle area
165 INPUT #1,SCANRAT:REM scan rate for data log
170 INPUT #1,PBAND1,PBAND2:REM preportional band for
furnace controls
175 INPUT #1,GVCONR1,GVCONR2,GVCONR3:REM INTEGRATION
RATES FOR GAS VALVE CONTRO
180 INPUT #1,RPMCONR:REM INTEGRATION RATE FOR CHOPPER
RPM
185 INPUT #1,FASPD,SLOSPD%:FASPDM=FASPD/60
187 INPUT #1,RGHWCON
188 INPUT #1,SKIP
189 INPUT #1,DIST
190 INPUT #1,PVMEDR:REM particle velocity median rate
constant
192 CLOSE #1
```

The array GCOMP is used to store the percentage of each component of the gas mixture. CPGTOT is used in the calculation of the gas mixture's Cp (specific heat at constant pressure). MPTR, SPTR, BLANK and BLOK are used to store shapes used in the graphic display.

Line 110 through 122 define several one-line functions. The pair of functions FNHI and FNLO are used to get the low byte and high byte of an integer number so that an OUTP or POKE command can be used send it to an I/O port or memory location. The FNCP function returns the value of Cp for the gas mixture at temperature T. The array CPGTOT contains the weighted averaged coefficients of the regression equations for all the gases present in the mixture.

Line 150 opens a special parameter file called "erode.def" and lines 160 through 192 read parameters from it. The only parameters which an operator might wish to change are NOZA the nozzle area, and SCANRAT which sets the frequency of data logging during an experiment. NOZA would only need to be altered if wear or replacement has altered the cross-sectional area of the particle stream nozzle.

Lines 230 to 290 are data statements containing the coefficients for polynomial approximation of the

Cps of several gases as a function of temperature:

```
200 REM initialization
220 ST%=128:REM toggle flag for safety shutoff
221 BS$=CHR$(8)
230 REM data for cp of gases
240 DATA 29.0,.2199e-2,.5723e-5,-2.871e-9:REM nitrogen
250 DATA 29.1,1.158e-2,-.6076e-5,1.311e-9:REM oxygen
260 DATA 36.11,4.233e-2,2.887e-5,7.464e-9:REM carbon
dioxide
270 DATA 28.95,.4110e-2,.3548e-5,-2.22e-9:REM carbon
monoxide
280 DATA 33.46,.688e-2,.7604e-5,-3.593e-9:REM water
vapor
290 DATA 38.91,3.904e-2,-3.104e-5,8.606e-9:REM sulfer
dioxide
```

Lines 300 to 395 request the current time and the composition of the test gas:

```
300 CLS
303 INPUT "    Operator ";OPNAM$
305 LOCATE 2:INPUT "Please enter the current time
 HH:MM:SS   ",T$
307 IF (MID$(T$,3,1)<>":") OR (MID$(T$,6,1)<>":") OR
LEN(T$)<>8 THEN 305
308 TIME$=T$
310 LOCATE 5
320 PRINT "enter composition of test gas:"
330 INPUT "          nitrogen....% ",GCOMP(1)
340 INPUT "            oxygen....% ",GCOMP(2)
350 INPUT "    carbon dioxide....% ",GCOMP(3)
360 INPUT "  carbon monoxide....% ",GCOMP(4)
370 INPUT "       water vapor....% ",GCOMP(5)
380 INPUT "    sulfur dioxide....% ",GCOMP(6)
385 SUM=0:FOR I=1 TO 6:SUM=SUM+GCOMP(I):NEXT I
390 IF INT(SUM*10) <>1000 THEN PRINT "     sum not
100%":GOTO 310
395 PRINT "                                "
```

If the operator enters a gas composition that does not sum to 100%, then line 390 causes this section to be repeated.

Lines 400 to 420 read the values of the Cp polynomial coefficients from the data statements in lines 240 - 290, weighting them by the corrosponding gas percentage. The sums formed in the array CGPTOT represent coefficients for a polynomial which evaluates to the Cp of the mixture gas at any temperature. The polynomial is of the form $(a_1 + a_2*T + a_3*T^2 + a_4*T^3)/22.4$ where $a_1$ - $a_4$ are the coefficients stored

in CGPTOT:

```
400 FOR J=1 TO 6
410 FOR I=1 TO 4:READ
CPG:CPGTOT(I)=CPGTOT(I)+CPG*GCOMP(J)/100:NEXT I
420 NEXT J
```

Lines 450 to 520 read descriptions of the test samples and erodant, as well as some general notes and TMPERSM the time to erode each sample:

```
450 LOCATE 5,40:PRINT "Enter Description of sample"
460 FOR SN=1 TO 4
470 ROW=SN+6
480 LOCATE ROW,40:PRINT "#";SN;": ";
490 LINE INPUT SDISCR$(SN)
500 NEXT SN
505 LOCATE 12,40:PRINT "Particle erodant type? :"
506 LOCATE 13,40:LINE INPUT "    : ",SDISCR$(9)
510 LOCATE 15,10:INPUT "Enter erode time per sample in
minutes ",TMPERSM
520 LOCATE 20,10:LINE INPUT "General notes:
",SDISCR$(10)
```

Lines 890 to 990 complete the initialization of the system:

```
890 GOSUB 9000:REM init tecmar
895 PRINT "":PRINT "          INITIALIZATION COMPLETE:
Please switch on the 220 volt mains ."
896 LINE INPUT "                                hit return key
when ready";DUMMY$
900 CLS:GOSUB 5000:REM draw & setup display graphics
910 REM reverse motor to pos zero
912 OUT TPPB%,PBDAT% OR &H40
914 GOSUB 50000:STRTM=TIMIN
916 GOSUB 50000:IF TIMIN<STRTM+.5 THEN PLAY
"O0132C":GOTO 916
918 OUT TPPB%,PBDAT% AND &H8F
920 INC=1:GOSUB 40680
990 NSP%=1:REM on screen setup pointer
```

After initializing the TecMar, the program pauses at line 896 to allow the operator to turn on the 220 supply for the furnace elements. The graphics are generated next at line 900, then the sample disc is moved to position zero. Since the computer cannot know the initial position of the sample disc it simply operates the motor in reverse for a sufficient time to ensure that it will have hit its reverse limit switch and come to rest, then runs it forward until the first index hole is detected. Because it may take some time,

a warbling sound is played during the reverse operation of the motor, to indicate that the program is operating correctly.

### 2.1.3 The main loop:

The control program's main loop starts at line 1000 and goes to line 1148, then skips to 2000 and continues to 2210, where it jumps back to 1000. If the setpoints have been achieved and the experiment started, then the forward jump occurs earlier, at line 1090, and jumps to 1800 instead of 2000. This means that now code from 1100 to 1148 will not be executed and code from 1800 to 2000 will be executed each time through the loop. The 1100 - 1148 code is involved with altering setpoints: You can't do this after the experiment begins. The code from 1800 - 2000 is involved with logging data to the printer during an experiment.

Lines 1000 to 1085 read all the real-time inputs: Main furnace, pre-heat furnace, and sample block temperatures, gas meter flows 1, 2 and 3, gas heater power input, and chopper and feed screw rpms:

```
1000 REM main loop
1005 REM input data
1006 LINE(X1,Y1)-(X2,Y2),0,B
1010 GOSUB 20100:REM t.c. #1 main furnace
1020 GOSUB 20200:REM t.c. #2 preheat furnace
1030 GOSUB 20300:REM t.c. #3 sample block
1040 GOSUB 10100:REM gas meter #1 main flow
1050 GOSUB 10200:REM gas meter #2 particle feeder
1060 GOSUB 10300:REM gas meter #3 SO2 flow
1063 GOSUB 10400:REM read gas heater power input
1065 TOTFLO=GASFLO1+GASFLO2+GASFLO3
1068 GOSUB 3100
1070 GOSUB 30000:REM read rpm of feed screw
1080 GOSUB 30100:REM read chopper rpm
1085 IF(SAMPOS%=0) AND (RPMSET>50) THEN GOSUB 30200
```

This line skips over the next section if the experiment is already underway:

```
1090 IF(EXPROC) THEN 1800:REM if experiment is under
way
```

Lines 1100 to 1148 are the part of the loop in which operator input is read and used to update the setpoints and display:

```
1100 REM change setpoints:
```

```
1105 GOSUB 40500
1110 Q$=INKEY$:IF Q$=" " THEN NSP%=NSP%+1
1112 COMM$=COMM$+Q$:COMM$=RIGHT$(COMM$,3)
1115 IF Q$=BS$ THEN NSP%=NSP%-1
1118 INC=0
1120 IF Q$="u" THEN INC=1
1122 IF Q$="U" THEN INC=10
1123 IF(Q$<>"") THEN IF ASC(Q$)=21 THEN INC=.1
1124 IF Q$="d" THEN INC=-1
1128 IF Q$="D" THEN INC=-10
1129 IF(Q$<>"") THEN IF ASC(Q$)=4 THEN INC=-.1
1130 IF NSP% > 8 THEN NSP%=8
1131 IF NSP%<1 THEN NSP%=1
1135 ON NSP% GOSUB 1150, 1170, 1200, 1250, 1300, 1350,
                   1400, 1450
1136 LINE(X1,Y1)-(X2,Y2),1,B
1140 IF((ABS(TSET1-TC1)<10) AND (ABS(TSET2-TC2)<10) AND
(ABS(GASET1-GASFLO1)<1) AND (ABS(GASET2-GASFLO2)<1) AND
(ABS(GASET3-GASFLO3)<.015)) THEN 1145 ELSE 1890
1145 LOCATE 20,27:PRINT "SETPOINTS ACHIEVED....begin
experiment?":SA%=1
1147 IF COMM$="YES" OR COMM$="yes" THEN
EXPROC=1:PFRPMN=RPM2:PFRPMX=RPM2
:LINE(X1,Y1)-(X2,Y2),0,B:GOSUB 6000
1148 GOTO 2000
```

If a key has been pressed since the last pass through the loop, it will be read into the string variable Q$ at line 1110. The variable COMM$ always contains the last three characters pressed. If the space bar has been pressed, then the integer variable NSP% is incremented, if backspace is pressed NSP% is decremented. Lines 1130 and 1131 limit the range of NSP% to 1 to 8. This variable indicates which of the 8 fields is to be updated. Line 1135 calls the appropriate display subroutine for the field indicated by NSP%. On subsequent passes, the user may enter Ctrlu, u, or U to increase or Ctrld, d, or D to decrease the value of the set-point field selected. The variable INC is set in lines 1120 to 1129. Line 1140 tests to see if the set points have been achieved (within 10 deg C for the furnace temperatures, 1 lpm for main gas flow, .015 lpm for the SO2 flow.

The display subroutines for the various fields are described below:

1150 This routine updates and displays the current sample position.

1170 This routine displays the chopper rpm, but only if the sample position is at zero.

1200 This routine updates and displays the main furnace temperature setpoint.

1250 This routine updates and displays the auxiliary furnace temperature setpoint.

1300 This routine updates and displays the main gas flow rate setpoint.

1350 This routine displays the particle entrainment gas flowrate.

1400 This routine updates and displays the SO2 gas flow rate setpoint.

1450 This routine updates and displays the gas heater power input setpoint.

As mentioned at the beginning of this section lines 1800 to 1890 are only executed when an experiment is underway, and not during setup procedures:

```
1800 GOSUB 50000
1820 IF EXPTM>SCANRAT*SCANS% THEN GOSUB
60500:SCANS%=SCANS%+1
1830 IF EXPTM>4*TMPERSM THEN 55000
1840 IF EXPTM>(SAMPOS%-1)*TMPERSM THEN INC=1:GOSUB
1150:LPRINT TAB(30);"SAMPLE #";SAMPOS%-1
1890 LOCATE 20,27:IF SA%=1 THEN SA%=0:PRINT "
                                          "
```

Line 1820 checks to see if it is time for a scan, and if so, calls the subroutine at 60500 to log a line of data. Line 1830 checks to see if all samples have been treated for the required length of time, and if so, it terminates the run by jumping to 55000, the wind down phase. The code at 55000 turns all the furnaces off and, by looping back to line 1000, continues logging data until the main furnace has cooled below 500 deg, then it prints a final report.

The code from line 2000 to 2210 relates to gas valve, gas heater, furnace power, and chopper rpm controls. These topics will be discussed in the following sections.

## 2.2 Sense and control subroutines

During operation, the control program is continually cycling through a loop with a period of about 1 second. As described above in 2.1.3, lines 1010 to 1090 of the main loop read various sensor inputs,

while the code from line 2000 to 2210 is largely responsible for computing and outputing corrections to control the things sensed. In the following sections the subroutines that read in and convert inputs and output control signals are described individually.

### 2.2.1 Thermocouples:

At the beginning of the main loop (1010 - 1030) three GOSUB statements call routines at 20100, 20200, 20300. These routines read and display the temperatures of the main furnace, the preheat furnace, and the sample block, respectively:

```
20100 TCHIN%=0:GOSUB 20000:TC1=TCDEGC:LOCATE
16,12,0:PRINT USING "####";TC1
20110 PUT(89,YPM1),BLANK,AND:YPM1=110-TC1/16:
PUT(88,YPM1),MPTR,OR:RETURN

20200 TCHIN%=1:GOSUB 20000:TC2=TCDEGC:LOCATE
16,20,0:PRINT USING "####";TC2
20210 PUT(153,YPM2),BLANK,AND:YPM2=110-TC2/16:
PUT(152,YPM2),MPTR,OR:RETURN

20300 TCHIN%=2:GOSUB 20000:TC3=TCDEGC:LOCATE
17,66,0:PRINT USING "####";TC3:RETURN
```

Each of these routines, in turn, calls a routine at 20000. This routine reads a thermocouple: Its input is an input channel number set in the integer variable TCHIN%, and its output on returning is a temperature in degrees Celsius stored in variable TCDEGC:

```
20000 REM read K type thermocouples
20010 GOSUB 10000
20020 TCKI%=INT(TMV):IF TCKI%>50 THEN TCKI%=50
20030 TCDEGC=TCDAT(TCKI%)+(TCDAT(TCKI%+1)
      TCDAT(TCKI%))*(TMV-TCKI%)
20040 TCHIN%=15:GOSUB 10000:ROOMT=TMV*10-273.15:
      TCDEGC=TCDEGC+ROOMT
20050 RETURN
```

The call to 10000 at line 20010 returns the voltage in millivolts on the selected thermocouple in variable TMV. This value is truncated, at line 20020, to the nearest millivolt and used as an index into an array of 50 temperatures corrosponding to outputs of 0 to 50 mv, in 1 mv steps, for a type K thermocouple. At line 20030, linear interpolation is then used to approximate the temperature for the actual value of TMV. The values of the temperature indicated by a type K thermocouple for whole number millivolt values, stored in array

TCDAT, are derived from tables in The Omega Temperature Measurement Handbook. The data statements at 9150 to 9180 are read into TCDAT during the initailization section of the preamble.

In line 20040 the temperature of the thermocouple junction block ( "isothermal block" ) is measured by reading the output of the AD590 temperature sensor on channel 15 of the TecMar interface. This is used to compensate the value read for the thermocouple. See section 1.2.3 for details.

The subroutine at 10000 is a general purpose routine to read the TecMar Lab Master analog inputs:

```
10000 REM read millivolts
10010 OUT TADLO%,TCHIN%
10020 OUT TADHI%,0
10030 WAIT TCONTLA%,128
10040 TVLL=INP(TADLO%):TVHH=INP(TADHI%)
10050 TVLL=TVLL AND 255: TVHH=TVHH AND 255
10060 TMV=(TVLL+256*TVHH)*50/4096
10070 RETURN
```

Input is the desired channel number, stored in variable TCHIN%, output is a voltage in millivolts stored in variable TMV.

### 2.2.2 Furnace Control

The heating elements of the two furnaces are controlled by turning them on and off in a mark-space cycle with a period of about ten seconds:

```
2100 REM furnaces
2110 MKSP%=MKSP%+1:IF MKSP%>10 THEN MKSP%=0
2120 TFDIF1=(TSET1-TC1)/PBAND1
2130 TFDIF2=(TSET2-TC2)/PBAND2
2140 IF(TFDIF1 > MKSP%) THEN GOSUB 40110 ELSE GOSUB
40300
2150 IF(TFDIF2 > MKSP%) THEN GOSUB 40210 ELSE GOSUB
40400
2155 GOSUB 40500
```

The variable MKSP% is incremented on each pass through the loop and reset when it reaches ten. TDIF1 and TDIF2 are error factors related to the difference between the temperature setpoints and actual temperatures measured for each of the two furnaces. The control system works as follows: If for example TDIF1 is negative, the furnace 1 element will never be turned on (the furnace is too hot). If TDIF1 is positive then the element will

be turned on on each pass through the loop in which MKSP% is less than TDIF1. This gives a crude preportional range for values of TDIF1 between 1 and 10. The parameter PBAND1, read in from the file erode.def is nominally set to 5, giving a preportional band of 50 degrees. PBAND2 simularly controls the preportional range of furnace 2, and is nominally set to 10, giving a range of 100 degrees. These values, which depend on heating rates and the thermal masses of the furnaces, were found empirically to give rapid heating with minimum overshoot.

The call to 40500 toggles the safety shutoff circuit. See section 1.2.2.

The calls to 40110 and 40300 turn furnace 1 on and off, those to 40210 and 40400 switch furnace 2:

```
40100 REM furnace control and safety shutoff
40110 REM heater #1 on
40120 PBDAT%=PBDAT% OR 4
40130 OUT TPPB%,PBDAT%
40140 RETURN

40200 REM heater #2 on
40210 PBDAT%=PBDAT% OR 8
40220 OUT TPPB%,PBDAT%
40230 RETURN

40300 REM heater #1 off
40310 PBDAT%=PBDAT% AND NOT(4)
40320 OUT TPPB%,PBDAT%
40330 RETURN

40400 REM heater #2 off
40410 PBDAT%=PBDAT% AND NOT(8)
40420 OUT TPPB%,PBDAT%
40430 RETURN
```

### 2.2.3 Matheson Gas Flow Meters:

Lines 1040 to 1060 of the main loop read the Matheson gas flow meters and display the results, by calling routines at 10100, 10200, 10300:

```
10100 TCHIN%=3:GOSUB 10000:GASFLO1=TMV:
      LOCATE 16,30,0:PRINT USING "##.#";GASFLO1
10110 PUT(233,YPM3),BLANK,AND:YPM3=110-GASFLO1*1.4:
      PUT(232,YPM3),MPTR,OR:RETURN

10200 TCHIN%=4:GOSUB 10000:GASFLO2=TMV*.4:
```

```
      LOCATE 16,38,0:PRINT USING "##.#";GASFLO2
10210 PUT(297,YPM4),BLANK,AND:YPM4=110-GASFLO2*3.5:
      PUT(296,YPM4),MPTR,OR:RETURN

10300 TCHIN%=5:GOSUB 10000:GASFLO3=TMV/100:
      LOCATE 16,46,0:PRINT USING ".###";GASFLO3
10310 PUT(361,YPM5),BLANK,AND:YPM5=110-GASFLO3*140:
      PUT(360,YPM5),MPTR,OR:RETURN
```

Again, as described in 2.2.1, the routine at 10000 is used to read the appropriate TecMar Lab Master analog input channel.

### 2.2.4 Gas Valve Control

The gas valves respond rapidly to changes in control voltage, so their response must be slowed somewhat to avoid instabilty in the control loop. Stability is achieved by using a preportional-integral control system. In this system, a scaled error term is summed into the previous value of the control voltage to obtain the new value, on each pass through the loop. This results in smoother, more gradual changes in control voltage, avoiding feedback instability:

```
2005 REM gas valves
2010 GVCON1=(GASET1-GASFLO1)*GVCONR1+GVCON1:
     IF GVCON1>4.9 THEN GVCON1=4.9
2020 IF GVCON1<0 THEN GVCON1=0
2030 GVCHAN%=1:GOSUB 40000:DAC1V=GVCON1:GOSUB 30400:
     REM gas valve 1

2035 GASET2=GASFLO2:REM manual control on this one
2040 GVCON2=(GASET2-GASFLO2)*GVCONR2+GVCON2:
     IF GVCON2>4.9 THEN GVCON2=4.9
2050 IF GVCON2<0 THEN GVCON2=0
2060 GVCHAN%=2:GOSUB 40000:DAC1V=GVCON2:GOSUB 30400:
     REM gas valve 2

2070 GVCON3=(GASET3-GASFLO3)*GVCONR3+GVCON3:IF
GVCON3>4.9 THEN GVCON3=4.9
2080 IF GVCON3<0 THEN GVCON3=0
2090 GVCHAN%=3:GOSUB 40000:DAC1V=GVCON3:GOSUB 30400:
     REM gas valve 3
```

GVCON1 is the control voltage value to sent to gas valve 1. GVCONR1 controls the preportional range for this valve (and determines stability). Note that preportional control has been defeated for valve 2 by inserting line 2035. This is because the particle feeder has its own (manual) flow control valves and a

computer controlled valve could not easily be installed.

As described in 1.2.6, a single DAC is used to control several gas valves by using analog sample and hold circuits and a four-way selector chip. The subroutine at 40000 selects the desired output channel, while the routine at 30400 outputs to the DAC:

```
30400 REM output to dac 1
30410 DACN%=(4.9-DAC1V)*2048/5
30420 OUT TDA1HI%,FNHI(DACN%):OUT TDA1LO%,FNLO(DACN%)
30430 RETURN

40000 REM select gas valve (lines 0,1 8255 port B)
40010 PBDAT%=(PBDAT% AND &HFC) OR (GVCHAN% AND 3)
40020 OUT TPPB%,PBDAT%
40030 RETURN
```

### 2.2.5 Screw Feed RPM:

As described in 1.2.6, The auger, within the Sylco powder feeder, which delivers powder into the gas stream, has been fitted with an optical sensor to measure its rotation rate. The call at 1070 to subroutine 30000 reads this rate in RPM and returns it in the variable RPM2:

```
30000 REM read rpm for counter #2
30005 LOCATE 6,66,0:PRINT USING "####";RPM2
30010 OUT TMCNTL%,&H12
30020 TLL=INP(TDATM%):THH=INP(TDATM%)
30025 IF (TLL OR THH)=0 THEN RPM2=0:RETURN
30030 RPM2=60*625001/(256*THH+TLL)
30035 IF RPM2>10000 THEN RPM2=0
30037 IF RPM2<PFRPMN THEN PFRPMN=RPM2
30038 IF RPM2>PFRPMX THEN PFRPMX=RPM2
30040 RETURN
```

Before This code will work properly, the AM9513 chip on the TecMar Labmaster motherboard must be programmed correctly. This is done in lines 9270 - 9290 of the Labmaster initializing routine which begins at line 9000:

```
9270 OUT TMCNTL%,2:REM access mode reg. #2
9280 REM active high edge trig., repaeting count, up
binary 1/16 MHZ
9290 OUT TDATM%,&HA8:OUT TDATM%,&HDC
```

See section 1.1.4 for more information about the AM9513.

## 2.2.6 Sample Positioning Motor:

During the setup phase of the main loop, the sample position motor can be operated at will. The routine at 1150 displays the current sample position and calls a routine at 40600 to move the disc if necessary. The routine at 1150 is also called automatically during the experiment run mode of the main loop at 1840. This moves the sample disc to the next sample position after the specified eroding time has elapsed. See section 2.1.3 for details of the main loop. The software of routine 40600 may seem somewhat more complex than needed to control a simple one speed reversible motor, using two solid-state switches: One would expect that it would be sufficient to,

a) reverse the motor to its reverse limit,

b) go foward until the next index hole is detected,

c) stop. Repeat b) until done.

Problems arose, however, with the inexpensive shaded-pole motor and chain drive which were used. When operated in the above manner, the system initially exhibited severe overshoot and hysteresis problems. To overcome these problems, without re-specifying the drive system, a software solution was attempted, successfully: By 'jogging' the motor with short pulses, it was possible to slow the motor drastically during approach to an index hole, essentially eliminating overshoot. Running the motor at this very slow speed at all times resulted in unacceptable delays in advancing the sample disc, so the motor had to run at full speed whenever possible, making it necessary for the software to anticipate the index holes, at least approximately, on time measurements only:

```
40600 REM move sample position motor
40610 IF INC=0 THEN RETURN
40620 SPEED=50:SKIP%=SKIP
40625 GOSUB 50000:STM=TIMIN
40630 FOR I=1 TO 200
40640 PLAY "o0164g"
40650 GOSUB 40500:GOSUB 40800
40660 IF ARRIVED THEN LOCATE 19,44,0:PRINT"er":GOTO
40750
40665 GOSUB 50000:IF TIMIN>STM+FASPDM THEN 40680
40670 NEXT I
40680 SPEED=15:SKIP%=0
40690 FOR I=1 TO SLOSPD%
```

```
40700 GOSUB 40500:GOSUB 40800
40710 IF ARRIVED THEN 40750
40720 NEXT I
40730 PBDAT%=PBDAT% AND &H8F:OUT TPPB%,PBDAT%
40750 INC=0:RETURN
40800 PBDAT%=PBDAT% AND &H8F:ARRIVED=0
40810 OUT TPPB%,PBDAT%
40820 IF INC>0 THEN PBDAT%=PBDAT% OR &H10
40830 IF INC<0 THEN PBDAT%=PBDAT% OR &H40
40835 OUT TPPB%,PBDAT%
40840 FOR J=1 TO 50
40850 IF J>=SPEED THEN OUT TPPB%,PBDAT% AND &H8F
40855 IF I<SKIP% THEN 40870
40860 IF (INP(TPPA%) AND 1) THEN
ARRIVED=1:PBDAT%=PBDAT% AND &H8F:OUT
TPPB%,PBDAT%:RETURN
40870 NEXT J
40880 RETURN
```

2.2.7 Chopper Speed Control:

The subroutine at 30100 reads the RPM of the particle stream chopper:

```
30100 REM read rpm for counter #3
30105 LOCATE 2,53,0
30107 IF SAMPOS%=0 THEN PRINT USING "CHOPPER ####
RPM";RPM3 ELSE PRINT"                    "
30110 OUT TMCNTL%,&H13
30120 TLL=INP(TDATM%):THH=INP(TDATM%)
30125 IF (TLL OR THH)=0 THEN RPM3=0: RETURN
30130 RPM3=30*62500!/(256*THH+TLL)
30135 IF RPM3>10000 THEN RPM3=0
30140 RETURN
```

See section 1.1.4 for more information on the operation of the AM9513 timer chip and 1.2.8 for details of the hardware for chopper speed control.

Lines 2160 to 2200 control output to the Ultracon motor controller:

```
2160 REM rpm of chopper
2170 RPMCON=(RPMSET-RPM3)*RPMCONR+RPMCON
2180 IF RPMCON > 4.9 THEN RPMCON=4.9
2190 IF RPMCON<0 THEN RPMCON=0
2195 IF SAMPOS%<>0 THEN RPMCON=0
2200 DAC2V=RPMCON:GOSUB 30500:REM dac #2 out
```

Line 2170 implements a simple preportional-integral controller. Lines 2180 set hard limits on the output voltage. Line 2195 turns the chopper off if position

zero is not selected: The chopper is only useful when the particle stream is allowed to pass through the hole at position zero of the sample disc. See sections 1.2.12 and 2.2.9 for details of particle velocity measurement using the chopper.

### 2.2.8 Gas Heater Power Control:

A call to 10400, at line 1063 ofthe main loop, reads the input power to the gas heater:

```
10400 REM read gas heater input power
10410 TCHIN%=6:GOSUB 10000:VRMS=TMV*5
10420 TCHIN%=7:GOSUB 10000:IRMS=TMV/4
10430 GHW=VRMS*IRMS:LOCATE 7,63,0
10440 IF IRMS<VRMS/25 AND VRMS>20 THEN GHWSET=0:LOCATE
8,66,0:PRINT USING "####";GHWSET:LOCATE 7,63,0:PRINT
"Failure!!" ELSE LOCATE 7,63,0:PRINT "          "
10450 RETURN
```

Lines 10410 and 10420 read the current and voltage through the gas heater on analog input channels 6 and 7 of the TecMar Lab Master interface. See sections 1.1.3 and 1.2.10 for descriptions of the TecMar interface and the gas heater power input sense hardware.

Lines 2092 to 2094 control power input to the gas heater:

```
2092 GHWCON=(GHWSET-GHW)*RGHWCON+GHWCON:IF GHWCON>100
THEN GHWCON=100
2093 IF GHWCON<0 THEN GHWCON=0
2094 PW%=430-GHWCON*4:GOSUB 30300
```

Line 2092 implements a simple preportional-integral controller. PW% is the integer number of timer ticks to count between the zero crossing trigger and firing the main power triac. See 1.2.11 for details of gas heater power control circuitry. The subroutine at 30300 actually sets the pulse-width used by timer number 5 of the AM9513 chip on the TecMar Lab Master interface:

```
30300 REM set pulse width
30310 OUT TMCNTL%,&HD
30320 OUT TDATM%,FNLO(PW%)
30330 OUT TDATM%,FNHI(PW%)
30340 RETURN
```

The initialization code at 9470 -9500 must be executed before this will work:

```
9470 OUT TMCNTL%,5:REM access mode reg. #5
```

```
9480 OUT TDATM%,&HA1:OUT TDATM%,&HDC
9490 REM arm counters 2,3,4,5
9495 PW%=430:GOSUB 30300
9500 OUT TMCNTL%,&H3E
```

A call to 3100, from line 1068 of the main loop, calculates the estimated gas temperature, based on the known flow rate and composition of the gas, and the measured power input:

```
3100 REM calculate estimated gas temps:
3105 IF GHWSET<=0  OR TOTFLO<1  THEN
GHWSET=0:TGHOUT=ROOMT:TGAS=ROOMT:GOTO 3150
3110 JPLGHO=GHWSET*60/GASFLO1
3120 FOR IT=1 TO 5:TGHOUT=JPLGHO/FNCP(TGHOUT):NEXT IT
3122 TGHOUT=TGHOUT+ROOMT
3130 JPLDIL=JPLGHO*GASFLO1/TOTFLO
3140 FOR IT=1 TO 5:TGAS=JPLDIL/FNCP(TGAS):NEXT IT
3142 TGAS=TGAS+ROOMT
3150 RTK=ROOMT+273.15
3160 TGASK=TGAS+273.15
3170 HOTFLO=TOTFLO*TGASK/RTK
3175 IF TGHOUT>920 THEN GHWSET=GHWSET-100:LOCATE
8,66,0:PRINT USING "####";GHWSET
3180 HGASV=HOTFLO/(60000!*NOZA):REM gas vel m/s
3185 LOCATE 2,43,0:PRINT USING "###.#";HGASV
3187 LOCATE 12,66,0:PRINT USING "####";TGHOUT
3189 LOCATE 14,66,0:PRINT USING "####";TGAS
3190 RETURN
```

Only the main gas flow is heated by the gas heater, the cooler particle carrier gas dilutes this flow, lowering the temperature of the mixture. In line 3110 JPLGHO represents the Joules per Litre of Hot (undiluted) gas. The variable JPLDIL represents the heat content of the diluted gas.

### 2.2.9 Particle Velocity Sensor Signal Analysis:

In line 1085 of the main loop, a call to 30200 is made if the sample disc is positioned at the hole (position zero) and the chopper is rotating at least 50 rpm:

```
30200 REM read particle velocity counter #4
30210 OUT TMCNTL%,&H14
30220 TLL=INP(TDATM%):THH=INP(TDATM%)
30230 TDELAY=TLL+256*THH
30233 WPV=PVMEDR
30235 IF TDELAY=0 OR TDELAY>1.4E+07/(RPM3+1) THEN
PVEL=0:WPV=.1*PVMEDR:GOTO 30244
30240 PVEL=(DIST/TDELAY)*1000000!
```

```
30243 IF PVEL>999 THEN PVEL =0
30244 MPV=MPV+WPV*SGN(PVEL-MPV)
30245 LOCATE 1,43,0:PRINT USING "###.#";MPV
30250 RETURN
```

Lines 30210 - 30230 read the am9513 timer #4 and obtain TDELAY, the time of flight of the first particles to trigger the acoustic sensor. The variable DIST contains the distance from the chopper to the acoustic sensor in meters. Due to the statistical nature of the data, line 30244 computes MPV, the median of many measurements, by simply incrementing or decrementing depending on whether the next measurement is greater or lesser than the current value of MPV.

```
1 REM HIGH TEMPERATURE CORROSION EROSION TEST RIG CONTROL PROGRAM
2 REM
3 REM      Author.....Geoff Park...phone (416) 690-4158
4 REM Copyright 1987 (c)  Mind/Machine Interface Systems
5 REM                     183 Chisholm Ave, Toronto, Ontario
6 REM                     M4C-4V9
7 REM                     last modified, 21 MAR 87
10 SCREEN 2:KEY OFF
20 ON ERROR GOTO 40500
100 REM definitions
105 DIM GCOMP(6),CPGTOT(4),SDISCR$(10),CESHEAD$(3),TMPERSM(4)
106 DIM MPTR(20),SPTR(20),BLANK(20),BLOK(50)
110 DEF FNHI(X)=INT(X/256)
120 DEF FNLO(X)=X-FNHI(X)*256
121 REM cp of gas mixture in j/l stp
122 DEF FNCP(T)=(CPGTOT(1)+CPGTOT(2)*T+CPGTOT(3)*T*T+CPGTOT(4)*T*T*T)/22.4
130 LINV=220*1.414:GnR=40:PI=3.14159:REM line voltage, gasheater resistance
135 NOZA=.0000367:REM nozzle area in m2
140 FF$=CHR$(12):LF$=CHR$(10):REM form feed and line feed
150 OPEN "i",#1,"erode.def"
160 INPUT #1, NOZA:REM nozzle area
165 INPUT #1,SCANRAT:REM scan rate for data log
170 INPUT #1,PBAND1,PBAND2:REM proportional band for furnace controls
175 INPUT #1,GVCONR1,GVCONR2,GVCONR3:REM INTEGRATION RATES FOR GAS VALVE CONTRO
180 INPUT #1,RPMCONR:REM INTEGRATION RATE FOR CHOPPER RPM
185 INPUT #1,FASPD,SLOSPD%:FASPDM=FASPD/60
187 INPUT #1,RGH%CON
188 INPUT #1,SKIP
189 INPUT #1,DIST
190 INPUT #1,PVMEDR:REM particle velocity median rate constant
191 INPUT #1,EXRPT :REM how many times to repeat entire sequence
192 FOR I=1 TO 6 : INPUT #1,GCOMP(I):NEXT I
194 FOR I=1 TO 10 : LINE INPUT #1,SDISCR$(I):NEXT I
196 FOR I=1 TO 4: INPUT #1,TMPERSM(I):NEXT I
198 CLOSE #1
200 REM initialization
220 ST%=128:REM toggle flag for safety shutoff
221 BS$=CHR$(8)
230 REM data for cp of gases
240 DATA 29.0,.2199e-2,.5723e-5,-2.871e-9:REM nitrogen
250 DATA 29.1,1.158e-2,-.6076e-5,1.311e-9:REM oxygen
260 DATA 36.11,4.233e-2,2.887e-5,7.464e-9:REM carbon dioxide
270 DATA 28.95,.411e-2,.3546e-5,-2.22e-9:REM carbon monoxide
280 DATA 33.46,.688e-2,.7604e-5,-3.593e-9:REM water vapor
290 DATA 38.91,3.904e-2,-3.104e-5,8.606e-9:REM sulfer dioxide
300 CLS
303 ER=1:EC=10:EL=30:EPR$="Operator: ":EDF$="":GOSUB 700:OPNAM$=ES$
305 ER=2:EC=10:EL=8:EPR$="Please enter the current time: ":EDF$=TIME$:GOSUB 700
306 T$=ES$
307 IF (MID$(T$,3,1)<>":") OR (MID$(T$,6,1)<>":") OR LEN(T$)<>8 THEN 305
308 TIME$=T$
310 LOCATE 5,1
320 PRINT "enter composition of test gas:"
330 ER=6:EC=2:EL=8:EPR$="        nitrogen....% ":EDF$=STR$(GCOMP(1)):GOSUB 700
335 GCOMP(1) = VAL(ES$)
340 ER=7:EC=2:EL=8:EPR$="          oxygen....% ":EDF$=STR$(GCOMP(2)):GOSUB 700
345 GCOMP(2) = VAL(ES$)
350 ER=8:EC=2:EL=8:EPR$="  carbon dioxide....% ":EDF$=STR$(GCOMP(3)):GOSUB 700
355 GCOMP(3) = VAL(ES$)
360 ER=9:EC=2:EL=8:EPR$=" carbon monoxide....% ":EDF$=STR$(GCOMP(4)):GOSUB 700
365 GCOMP(4) = VAL(ES$)
```

```
370 ER=10:EC=2:EL=8:EPR$="     water vapor....% ":EDF$=STR$(GCOMP(5)):GOSUB 700
375 GCOMP(5) = VAL(ES$)
380 ER=11:EC=2:EL=8:EPR$="  sulfur dioxide....% ":EDF$=STR$(GCOMP(6)):GOSUB 700
383 GCOMP(6) = VAL(ES$)
385 SUM=0:FOR I=1 TO 6:SUM=SUM+GCOMP(I):NEXT I
390 IF INT(SUM*10) <>1000 THEN PRINT "     sum not 100%":GOTO 310
395 PRINT "                              "
450 LOCATE 5,40:PRINT "Enter Description of sample"
460 FOR SN=1 TO 4
470 ER=SN+6:EC=40:EL=30
480 EPR$="#"+STR$(SN)+": ":EDF$=SDISCR$(SN):GOSUB 700
490 SDISCR$(SN) = ES$
500 NEXT SN
505 ER=12:EC=40:EL=20:EPR$="Erocant type? :":EDF$=SDISCR$(9):GOSUB 700:SDISCR$(9)=ES$
506 FOR I = 1 TO 4
510 ER=14+I:EC=10:EL=6:EPR$="Enter erode time for sample"+STR$(I)+" in minutes: "
511 EDF$=STR$(TMPERSM(I)):GOSUB 700:TMPERSM(I)=VAL(ES$)
515 NEXT I
516 ER=19:EC=10:EL=6:EPR$="Data log rate (minutes): ":EDF$=STR$(SCANRAT):GOSUB 700:SCANRAT = VAL(ES$)
517 ER=19:EC=50:EL=6:EPR$="Repeat experiment ":EDF$=STR$(EXRPT):GOSUB 700:EXRPT = VAL(ES$)
520 ER=20:EC=10:EL=50:EPR$="General notes: ":EDF$=SDISCR$(10):GOSUB 700
530 SDISCR$(10)=ES$
540 ER=21:EC=32:EL=3:EPR$="All OK? ":EDF$="Yes":GOSUB 700
550 IF ES$ <> "Yes" THEN 305
552 FOR J=1 TO 6
554 FOR I=1 TO 4:READ CPG:CPGTOT(I)=CPGTOT(I)+CPG*GCOMP(J)/100:NEXT I
556 NEXT J
650 OPEN "o",#1,"erode.def"
660 PRINT #1, NOZA:REM nozzle area
665 PRINT #1,SCANRAT:REM scan rate for data log
670 PRINT #1,PBAND1,PBAND2:REM preportional band for furnace controls
675 PRINT #1,GVCONR1,GVCONR2,GVCONR3:REM INTEGRATION RATES FOR GAS VALVE CONTRO
680 PRINT #1,RPMCONR:REM INTEGRATION RATE FOR CHOPPER RPM
685 PRINT #1,FASPD,SLOSPD%:FASPDM=FASPD/60
687 PRINT #1,RGnWCON
688 PRINT #1,SKIP
689 PRINT #1,DIST
690 PRINT #1,PVMEDR
691 PRINT #1,EXRPT :REM how many times to repeat entire sequence
692 FOR I=1 TO 6 : PRINT #1,GCOMP(I):NEXT I
694 FOR I=1 TO 10 : PRINT #1,SDISCR$(I):NEXT I
696 FOR I=1 TO 4: PRINT #1,TMPERSM(I):NEXT I:PRINT #1," "
698 CLOSE #1
699 GOTO 890
700 LOCATE ER,EC:PRINT EPR$;
705 ES = EC+LEN(EPR$)+1:EE=ES+EL
710 ES$=EDF$:PRINT "[";ES$;STRING$(EL-LEN(ES$)," ");"]"
715 EK$ = INKEY$: IF EK$ = "" THEN 715
718 IF EK$ = STRING$(1,13) THEN 760
719 ES$ = "":LOCATE ER,ES:PRINT STRING$(EL," ");
720 WHILE EK$ <> STRING$(1,13)
725 EL = ES+LEN(ES$)
730 IF EL < EE THEN ES$ = ES$ + EK$:LOCATE ER,ES:PRINT cS$;
740 EK$ = INKEY$: IF EK$ = "" GOTO 740
743 IF EK$ = STRING$(1,8) AND EL > ES THEN ES$ =LEFT$(ES$,LEN(ES$)-1):EK$="":LOCATE ER,ES+LEN(ES$):PRINT " ";
744 EL = ES+LEN(ES$)
750 WEND
760 LOCATE ER,ES-1:PRINT " ";ES$;:LOCATE ER,EE:PRINT "  "
770 RETURN
890 GOSUB 9000:REM init tecmar
895 PRINT "":PRINT "         INITIALIZATION COMPLETE: Please switch on the 220 volt mains ."
```

```
896 LINE INPUT "                              hit return key when ready";DUMMY$
900 CLS:GOSUB 5000:REM draw & setup display graphics
910 REM reverse motor to pos zero
912 OUT TPPB%,PBDAT% OR &H40:SAMPOS%=0:SCANS%=0
914 GOSUB 50000:STRTM=TIMIN
916 GOSUB 50000:IF TIMIN(STRTM+.5 THEN PLAY "O0132C":GOTO 916
918 OUT TPPB%,PBDAT% AND &H8F
920 INC=1:GOSUB 40680
930 IF EXPROC THEN GOSUB 6000
990 NSP%=1:REM on screen setup pointer
995 SMTIM = 0
1000 REM main loop
1005 REM input data
1006 LINE(X1,Y1)-(X2,Y2),0,B
1010 GOSUB 20100:REM t.c. #1 main furnace
1020 GOSUB 20200:REM t.c. #2 preheat furnace
1030 GOSUB 20300:REM t.c. #3 sample block
1040 GOSUB 10100:REM gas meter #1 main flow
1050 GOSUB 10200:REM gas meter #2 particle feeder
1060 GOSUB 10300:REM gas meter #3 SO2 flow
1063 GOSUB 10400:REM read gas heater power input
1065 TOTFLO=GASFLO1+GASFLO2+GASFLO3
1068 GOSUB 3100
1070 GOSUB 30000:REM read rpm of feed screw
1080 GOSUB 30100:REM read chopper rpm
1085 IF(SAMPOS%=0) AND (RPMSET)50) THEN GOSUB 32000
1086 Q$=INKEY$:IF Q$=" " THEN NSP%=NSP%+1
1087 COMM$=COMM$+Q$:COMM$=RIGHT$(COMM$,3)
1088 LOCATE 20,55:PRINT "Command: [";COMM$;"]"
1090 IF(EXPROC) THEN 1600:REM if experiment is under way
1100 REM change setpoints:
1105 GOSUB 40500
1115 IF Q$=BS$ THEN NSP%=NSP%-1
1118 INC=0
1120 IF Q$="u" THEN INC=1
1122 IF Q$="U" THEN INC=10
1123 IF(Q$()"") THEN IF ASC(Q$)=21 THEN INC=.1
1124 IF Q$="d" THEN INC=-1
1126 IF Q$="D" THEN INC=-10
1129 IF(Q$()"") THEN IF ASC(Q$)=4 THEN INC=-.1
1130 IF NSP% ) 8 THEN NSP%=8
1131 IF NSP%(1 THEN NSP%=1
1135 ON NSP% GOSUB 1150,1170,1200,1250,1300,1350,1400,1450
1136 LINE(X1,Y1)-(X2,Y2),1,B
1140 IF((ABS(TSET1-TC1)(10) AND (ABS(TSET2-TC2)(10) AND (ABS(GASET1-GASFLO1)(1) AND (ABS(GASET2-GASFLO2)(1) AND (ABS(GASET3-GASFLO3)
1145 LOCATE 20,10:PRINT "SETPOINTS ACHIEVED....begin experiment?":SA%=1
1147 IF COMM$="YES" OR COMM$="yes" THEN EXPROC=1:PFRPM=RPM2:PFRPMX=RPM2:LINE(X1,Y1)-(X2,Y2),0,B:GOSUB 6000
1148 GOTO 2000
1150 LOCATE 19,44,0:SAMPOS%=SAMPOS%+INC:PRINT USING "##";SAMPOS%:IF((SAMPOS%(0) OR (SAMPOS%)5)) THEN SAMPOS%=5
1153 X1=350:Y1=143:X2=360:Y2=152
1155 LOCATE 3,53,0:IF SAMPOS%()0 THEN PRINT "                "
1156 GOSUB 40600:RETURN
1170 IF(SAMPOS%()0 AND Q$=" ") THEN NSP%=NSP%+1:RETURN
1171 IF(SAMPOS%()0 AND Q$=BS$) THEN NSP%=NSP%-1:RETURN
1175 LOCATE 3,53,0:PRINT USING " SPEED  #### SET";RPMSET:RPMSET=RPMSET+10*INC
1176 X1=480:Y1=24:X2=512:Y2=15
1177 IF RPMSET(0 THEN RPMSET=0:RPMCON=0
1180 RETURN
1200 LOCATE 17,12,0:PRINT USING "####";TSET1:TSET1=TSET1+10*INC
1205 X1=88:Y1=136:X2=120:Y2=127
1210 IF TSET1)1120 THEN TSET1=1120
```

```
1212 IF TSET1(0 THEN TSET1=0
1215 PUT(184,YPS1),BLANK,AND:YPS1=110-TSET1/16:PUT(184,YPS1),SPTR,OR
1220 RETURN
1250 LOCATE 17,20,0:PRINT USING "####";TSET2:TSET2=TSET2+10*INC
1255 X1=152:Y1=136:X2=184:Y2=127
1260 IF TSET2)1120 THEN TSET2=1120
1262 IF TSET2(0 THEN TSET2=0
1265 PUT(168,YPS2),BLANK,AND:YPS2=110-TSET2/16:PUT(168,YPS2),SPTR,OR
1270 RETURN
1300 LOCATE 17,30,0:PRINT USING "##.#";GASET1:GASET1=GASET1+.5*INC:IF GASET1(0 THEN GASET1=0
1305 X1=232:Y1=136:X2=264:Y2=127
1307 IF GASET1)10 THEN X1=250
1310 IF GASET1)50 THEN GASET1=50
1315 PUT(248,YPS3),BLANK,AND:YPS3=110-GASET1*1.4:PUT(248,YPS3),SPTR,OR
1320 RETURN
1350 LOCATE 17,38,0:PRINT USING "##.#";GASET2:REM disable GASET2=GASET2+.2*INC:IF GASET2(0 THEN GASET2=0
1355 X1=296:Y1=136:X2=328:Y2=127
1357 IF GASET2)10 THEN X1=294
1360 IF GASET2)20 THEN GASET2=20
1365 PUT(312,YPS4),BLANK,AND:YPS4=110-GASET2*3.5:PUT(312,YPS4),SPTR,OR
1370 RETURN
1400 LOCATE 17,46,0:PRINT USING ".###";GASET3:GASET3=GASET3+.005*INC:IF GASET3(0 THEN GASET3=0
1405 X1=360:Y1=136:X2=392:Y2=127
1410 IF GASET3).5 THEN GASET3=.5
1415 PUT(376,YPS5),BLANK,AND:YPS5=110-GASET3*140
1416 PUT(376,YPS5),SPTR,OR
1420 RETURN
1450 LOCATE 8,66,0:PRINT USING "####";GHWSET:GHWSET=GHWSET+INC*5:IF GHWSET(0 THEN GHWSET=0
1455 X1=520:Y1=64:X2=552:Y2=55
1460 IF GHWSET)1500 THEN GHWSET=1500
1490 RETURN
1600 GOSUB 52000
1820 IF COM$ = "end" THEN EXPT = 0: GOTO 55000
1830 IF EXPTM)(TMPERSM(1)+TMPERSM(2)+TMPERSM(3)+TMPERSM(4)) THEN 55000
1840 IF EXPTM)SMTIM THEN INC=1:GOSUB 1150:LPRINT TAB(30);"SAMPLE #";SAMPOS%-1
1845 IF EXPTM ) SMTIM THEN SMTIM = SMTIM + TMPERSM(SAMPOS%-1)
1850 IF EXPTM)SCANRAT*SCANS% THEN GOSUB 60500:SCANS%=SCANS%+1
1890 LOCATE 20,27:IF SA%=1 THEN SA%=0:PRINT "                                    "
2000 REM controls
2002 GOSUB 40500
2005 REM gas valves
2010 GVCON1=(GASET1-GASFLO1)*GVCONR1+GVCON1:IF GVCON1)4.9 THEN GVCON1=4.9
2020 IF GVCON1(0 THEN GVCON1=0
2030 GVCHAN%=1:GOSUB 40000:DAC1V=GVCON1:GOSUB 30400:REM gas valve 1
2035 GASET2=GASFLO2:REM manual control on this one
2040 GVCON2=(GASET2-GASFLO2)*GVCONR2+GVCON2:IF GVCON2)4.9 THEN GVCON2=4.9
2050 IF GVCON2(0 THEN GVCON2=0
2060 GVCHAN%=2:GOSUB 40000:DAC1V=GVCON2:GOSUB 30400:REM gas valve 2
2070 GVCON3=(GASET3-GASFLO3)*GVCONR3+GVCON3:IF GVCON3)4.9 THEN GVCON3=4.9
2080 IF GVCON3(0 THEN GVCON3=0
2090 GVCHAN%=3:GOSUB 40000:DAC1V=GVCON3:GOSUB 30400:REM gas valve 3
2092 GHWCON=(GHWSET-GHW)*RGHWCON+GHWCON:IF GHWCON)100 THEN GHWCON=100
2093 IF GHWCON(0 THEN GHWCON=0
2094 PW%=430-GHWCON*4:GOSUB 30300
2100 REM furnaces
2110 MKSP%=MKSP%+1:IF MKSP%)10 THEN MKSP%=0
2120 TFDIF1=(TSET1-TC1)/PBAND1
2130 TFDIF2=(TSET2-TC2)/PBAND2
2140 IF(TFDIF1 ) MKSP%) THEN GOSUB 40110 ELSE GOSUB 40300
2150 IF(TFDIF2 ) MKSP%) THEN GOSUB 40210 ELSE GOSUB 40400
2155 GOSUB 40500
```

```
2160 REM rpm of chopper
2170 RPMCON=(RPMSET-RPM3)*RPMCONR+RPMCON
2180 IF RPMCON ) 4.9 THEN RPMCON=4.9
2190 IF RPMCON(0 THEN RPMCON=0
2195 IF SAMPOS%()0 THEN RPMCON=0
2200 DAC2V=RPMCON:GOSUB 30500:REM dac #2 out
2210 GOTO 1000
3100 REM calculate estimated gas temps:
3105 IF GHWSET(=0  OR TOTFLO(1  THEN GHWSET=0:TGHOUT=ROOMT:TGAS=ROOMT:GOTO 3150
3110 JPLGHO=GHWSET*60/GASFLO1
3120 FOR IT=1 TO 5:TGHOUT=JPLGHO/FNCP(TGHOUT):NEXT IT
3122 TGHOUT=TGHOUT+ROOMT
3130 JPLDIL=JPLGHO*GASFLO1/TOTFLO
3140 FOR IT=1 TO 5:TGAS=JPLDIL/FNCP(TGAS):NEXT IT
3142 TGAS=TGAS+ROOMT
3150 RTK=ROOMT+273.15
3160 TGASK=TGAS+273.15
3170 HOTFLO=TOTFLO*TGASK/RTK
3175 IF TGHOUT)920 THEN GHWSET=GHWSET-100:LOCATE 8,66,0:PRINT USING "####";GHWSET
3180 HGASV=HOTFLO/(60000!*AOIA):REM gas vel m/s
3185 LOCATE 2,43,0:PRINT USING "###.#";HGASV
3187 LOCATE 12,66,0:PRINT USING "####";TGHOUT
3189 LOCATE 14,66,0:PRINT USING "####";TGAS
3190 RETURN
5000 REM draw and setup display graphics
5006 GET(0,8)-(15,0),BLANK:LOCATE 1,1,0:PRINT" m s"
5007 GET(7,8)-(15,0),MPTR:GET(23,8)-(31,0),SPTR
5008 LOCATE 1,1,0:PRINT "     "
5010 LOCATE 13,28,0:PRINT"SAMPLE POSITION:"
5020 LOCATE 1,25,0:PRINT"PARTICLE VELOCITY:"
5030 LOCATE 1,48,0:PRINT"m/s"
5040 LOCATE 1,71,0:PRINT DATE$
5050 LOCATE 2,20,0:PRINT"ESTIMATED GAS VELOCITY:"
5060 LOCATE 2,48,0:PRINT"m/s"
5070 LOCATE 4,14,0:PRINT"FURNACES"
5080 LOCATE 4,33,0:PRINT"GAS FLOWS l/m"
5090 LOCATE 5,12,0:PRINT"MAIN  PRE-HEAT"
5100 LOCATE 5,30,0:PRINT"MAIN  P. FEED   SO2"
5110 LOCATE 6,16,0:PRINT"1200"
5120 LOCATE 6,28,0:PRINT"50"
5130 LOCATE 6,36,0:PRINT"20"
5140 LOCATE 6,44,0:PRINT".5"
5150 LOCATE 6,55,0:PRINT"SCREW FEED:     RPM"
5160 LOCATE 7,52,0:PRINT"GAS HEATER"
5170 LOCATE 8,54,0:PRINT"POWER INPUT:     WATTS"
5180 LOCATE 10,52,0:PRINT"ESTIMATED GAS"
5190 LOCATE 11,52,0:PRINT"HEATER OUTLET"
5200 LOCATE 12,54,0:PRINT"TEMPERATURE:     deg C"
5210 LOCATE 13,52,0:PRINT"FINAL TEMP."
5220 LOCATE 14,54,0:PRINT"DILUTED GAS:     deg C"
5230 LOCATE 15,17,0:PRINT"100"
5240 LOCATE 15,29,0:PRINT"0"
5250 LOCATE 15,37,0:PRINT"0"
5260 LOCATE 15,45,0:PRINT"0"
5270 LOCATE 16,2,0:PRINT"MEASURED"
5280 LOCATE 16,52,0:PRINT"SAMPLE BLOCK"
5290 LOCATE 17,2,0:PRINT"SETPOINT"
5300 LOCATE 17,54,0:PRINT"TEMPERATURE:     deg C"
5310 LINE(80,39)-(192,23),,B
5320 LINE(224,39)-(400,23),,B
5330 LINE(80,39)-(120,119),,B
```

```
5340 LINE(152,39)-(184,119),,B
5350 LINE(232,39)-(264,119),,B
5360 LINE(296,39)-(328,119),,B
5370 LINE(360,39)-(392,119),,B
5400 LINE(88,118)-(96,110),,BF
5410 LINE-(104,114)
5420 LINE-(96,118)
5430 PAINT(102,114),1
5440 LINE(120,118)-(112,110),,BF
5450 LINE(112,110)-(104,114)
5460 LINE-(112,118)
5470 PAINT(106,114),1
5480 PUT(89,110),MPTR
5490 PUT(112,110),SPTR
5500 GET(88,110)-(104,118),MPTR
5520 GET(104,110)-(120,118),SPTR
5530 YPS1=110:YPS2=110:YPS3=110:YPS4=110:YPS5=110
5540 YPM1=110:YPM2=110:YPM3=110:YPM4=110:YPM5=110
5550 LINE(268,167)-(356,176),,BF
5560 GET (268,167)-(356,176),BLOK
5570 LINE(268,167)-(356,176),0,BF
5580 LOCATE 22,35,0:PRINT"setup mode"
5590 PUT(268,167),BLOK
5600 LOCATE 24,16,0:PRINT"SPACE BAR & BACKSPACE KEYS SELECT SETUP POSITION";
5610 LOCATE 25,8,0:PRINT"u=up d=down U=up*100 D=down*100  [Ctrl]u=up*.1  [Ctrl]d=down*.1";
5620 CESHEAD$(1)="PMAL Canmet High Temperature Corrosion-Erosion Test Facility"
5630 CESHEAD$(2)="Designed & constructed by the Centre for Energy Studies, Halifax N.S., 1984"
5640 RETURN
6000 LOCATE 24,15,0:PRINT"                                                    ";
6010 LOCATE 25,1,0:PRINT"                                                                  ";
6015 LOCATE 20,10,0:PRINT"                                                        ";
6020 LINE(268,167)-(356,176),0,BF
6030 LOCATE 22,35,0:PRINT" run mode ";
6040 PUT(268,167),BLOK
6045 INC=1-SAMPOS%:GOSUB 1150:IF SAMPOS%()1 THEN 6045
6050 GOSUB 50000:STRTM=TIMIN
6055 GOSUB 60400:REM header 1
6060 RETURN
9000 REM initialize Tecmar Labmaster
9010 REM Tecmar Definitions:
9020 TDA1LO%=&H710:REM low byte of d/a #1
9030 TDA1HI%=&H711:REM high byte of d/a #1
9040 TDA2LO%=&H712:REM low byte of d/a #2
9050 TDA2HI%=&H713:REM high byte of d/a #2
9060 TCONTLA%=&H714:REM a/d control/status byte
9070 TADLO%=&H715:REM a/d low byte/channel no. on write
9080 TADHI%=&H716:REM a/d high byte/start convert on write
9090 TDATM%=&H718:REM r/w data port am9513 timer
9100 TMCNTL%=&H719:REM r/w control port am9513 timer
9110 TPPA%=&H71C:REM r/w parallel port A of 8255
9120 TPPB%=&H71D:REM r/w parallel port B of 8255
9130 TPPC%=&H71E:REM r/w parallel port C of 8255
9140 TPPCNTL%=&H71F:REM write 8255 control port
9145 DIM TCDAT(50)
9150 DATA 0,25,49.5,73.6,97.7,122,145.6,171.5
9155 DATA 196.6,246.3,270.8,295.0,319.1,343.0,366.9,390.6
9160 DATA 414.3,437.9,461.5,485.0,508.4,531.9,555.3,578.8
9165 DATA 602.3,625.9,649.5,673.2,697.0,720.8,744.8,769.0
9170 DATA 793.2,817.7,842.3,867.0,891.9,916.9,942.2,967.5
9175 DATA 993.1,1018.8,1044.7,1070.8,1097.1,1123.7,1150.4,1177.4
9180 DATA 1204.7,1232.3
```

```
9185 FOR K=0 TO 49
9190 READ TCDAT(K)
9195 NEXT K
9200 REM init for a/d
9210 OUT TCONTLA%,128
9220 REM init parallel port
9230 OUT TPPCNTL%,&H90
9250 REM setup am9513 counter
9260 REM for rpm measurement with counter #2 (feed screw)
9270 OUT TMCNTL%,2:REM access mode reg. #2
9280 REM active high edge trig., repaeting count, up binary 1/16 MHZ
9290 OUT TDATM%,&HA8:OUT TDATM%,&HDC
9300 REM same for counter #3 (particle stream chopper)
9310 OUT TMCNTL%,3:REM access mode reg. #3
9320 OUT TDATM%,&HA8:OUT TDATM%,&HDC
9330 REM clear load registers 2&3
9340 OUT TMCNTL%,&HA:REM access load reg. #2
9350 OUT TDATM%,0:OUT TDATM%,0:REM clear it
9360 OUT TMCNTL%,&HB:REM access load reg. #3
9370 OUT TDATM%,0:OUT TDATM%,0:REM clear it
9380 REM setup timer #4 for particle velocity:
9390 REM set t #4 for:
9400 REM active high level gate,count only during active level,up binary 1mhz
9410 OUT TMCNTL%,4:REM access mode reg. #4
9420 OUT TDATM%,&HA8:OUT TDATM%,&H3B
9430 REM clear load reg. #4
9440 OUT TMCNTL%,&HC:REM access load reg. #4
9450 OUT TDATM%,0:OUT TDATM%,0:REM clear it
9460 REM setup counter #5 for pulse width modulation (gas heater triac )
9470 OUT TMCNTL%,5:REM access mode reg. #5
9480 OUT TDATM%,&HA1:OUT TDATM%,&HDC
9490 REM arm counters 2,3,4,5
9495 PW%=430:GOSUB 30300
9500 OUT TMCNTL%,&H3E
9510 RETURN
10000 REM read millivolts
10010 OUT TADL0%,TCHIN%
10020 OUT TADHI%,0
10030 WAIT TCONTLA%,128
10040 TVLL=INP(TADL0%):TVHH=INP(TADHI%)
10050 TVLL=TVLL AND 255: TVHH=TVHH AND 255
10060 TMV=(TVLL+256*TVHH)*50/4096
10070 RETURN
10100 TCHIN%=3:GOSUB 10000:GASFL01=TMV:LOCATE 16,30,0:PRINT USING "**.*";GASFL01
10110 PUT(233,YPM3),BLANK,AND:YPM3=110-GASFL01*1.4:PUT(232,YPM3),MPTR,OR:RETURN
10200 TCHIN%=4:GOSUB 10000:GASFL02=TMV*.4:LOCATE 16,38,0:PRINT USING "**.*";GASFL02
10210 PUT(297,YPM4),BLANK,AND:YPM4=110-GASFL02*3.5:PUT(296,YPM4),MPTR,OR:RETURN
10300 TCHIN%=5:GOSUB 10000:GASFL03=TMV/100:LOCATE 16,46,0:PRINT USING ".***";GASFL03
10310 PUT(361,YPM5),BLANK,AND:YPM5=110-GASFL03*140:PUT(360,YPM5),MPTR,OR:RETURN
10400 REM read gas heater input power
10410 TCHIN%=6:GOSUB 10000:VRMS=TMV*5
10420 TCHIN%=7:GOSUB 10000:IRMS=TMV/4
10430 GHW=VRMS*IRMS:LOCATE 7,63,0
10440 IF IRMS(VRMS/25 AND VRMS)20 THEN GHWSET=0:LOCATE 8,66,0:PRINT USING "####";GHWSET:LOCATE 7,63,0:PRINT "Failure!!" ELSE LOCATE 7
10450 RETURN
20000 REM read K type thermocouples
20010 GOSUB 10000
20020 TCKI%=INT(TMV):IF TCKI%)50 THEN TCKI%=50
20030 TCDEGC=TCDAT(TCKI%)+(TCDAT(TCKI%+1)-TCDAT(TCKI%))*(TMV-TCKI%)
20040 TCHIN%=15:GOSUB 10000:ROOMT=TMV*10-273.15:TCDEGC=TCDEGC+ROOMT
20050 RETURN
```

```
20100 TCHIN%=0:GOSUB 20000:TC1=TCDEGC:LOCATE 16,12,0:PRINT USING "####";TC1
20110 PUT(89,YPM1),BLANK,AND:YPM1=110-TC1/16:PUT(88,YPM1),MPTR,OR:RETURN
20200 TCHIN%=1:GOSUB 20000:TC2=TCDEGC:LOCATE 16,20,0:PRINT USING "####";TC2
20210 PUT(153,YPM2),BLANK,AND:YPM2=110-TC2/16:PUT(152,YPM2),MPTR,OR:RETURN
20300 TCHIN%=2:GOSUB 20000:TC3=TCDEGC:LOCATE 17,66,0:PRINT USING "####";TC3:RETURN
30000 REM read rpm for counter #2
30005 LOCATE 6,66,0:PRINT USING "####";RPM2
30010 OUT TMCNTL%,&H12
30020 TLL=INP(TDATM%):THH=INP(TDATM%)
30025 IF (TLL OR THH)=0 THEN RPM2=0:RETURN
30030 RPM2=60*62500!/(256*THH+TLL)
30035 IF RPM2)10000 THEN RPM2=0
30037 IF RPM2(PFRPMN THEN PFRPMN=RPM2
30038 IF RPM2)PFRPMX THEN PFRPMX=RPM2
30040 RETURN
30100 REM read rpm for counter #3
30105 LOCATE 2,53,0
30107 IF SAMPOS%=0 THEN PRINT USING "CHOPPER #### RPM";RPM3 ELSE PRINT"
30110 OUT TMCNTL%,&H13
30120 TLL=INP(TDATM%):THH=INP(TDATM%)
30125 IF (TLL OR THH)=0 THEN RPM3=0: RETURN
30130 RPM3=30*62500!/(256*THH+TLL)
30135 IF RPM3)10000 THEN RPM3=0
30140 RETURN
30200 REM read particle velocity counter #4
30210 OUT TMCNTL%,&H14
30220 TLL=INP(TDATM%):THH=INP(TDATM%)
30230 TDELAY=TLL+256*THH
30233 WPV=PVMEDR
30235 IF TDELAY=0 OR TDELAY)1.4E+07/(RPM3+1) THEN PVEL=0:WPV=.1*PVMEDR:GOTO 30244
30240 PVEL=(DIST/TDELAY)*1000000!
30243 IF PVEL)999 THEN PVEL =0
30244 MPV=MPV+WPV*SGN(PVEL-MPV)
30245 LOCATE 1,43,0:PRINT USING "###.#";MPV
30250 RETURN
30300 REM set pulse width
30310 OUT TMCNTL%,&HD
30320 OUT TDATM%,FNLO(PW%)
30330 OUT TDATM%,FNHI(PW%)
30340 RETURN
30400 REM output to dac 1
30410 DACN%=(4.9-DAC1V)*2048/5
30420 OUT TDA1HI%,FNHI(DACN%):OUT TDA1LO%,FNLO(DACN%)
30430 RETURN
30500 REM output to dac 2
30510 DACN%=DAC2V*2048/5
30520 OUT TDA2HI%,FNHI(DACN%):OUT TDA2LO%,FNLO(DACN%)
30530 RETURN
40000 REM select gas valve channel (lines 0,1 8255 port B)
40010 PBDAT%=(PBDAT% AND &HFC) OR (GVCHAN% AND 3)
40020 OUT TPPB%,PBDAT%
40030 RETURN
40100 REM furnace control and safety shutoff
40110 REM heater #1 on
40120 PBDAT%=PBDAT% OR 4
40130 OUT TPPB%,PBDAT%
40140 RETURN
40200 REM heater #2 on
40210 PBDAT%=PBDAT% OR 8
40220 OUT TPPB%,PBDAT%
40230 RETURN
```

```
40300 REM heater #1 off
40310 PBDAT%=PBDAT% AND NOT(4)
40320 OUT TPPB%,PBDAT%
40330 RETURN
40400 REM heater #2 off
40410 PBDAT%=PBDAT% AND NOT(8)
40420 OUT TPPB%,PBDAT%
40430 RETURN
40500 REM toggle safety shutoff (pb7)
40505 LOCATE 2,71,0:PRINT TIME$
40510 IF ST%=128 THEN 40540
40520 PBDAT%=PBDAT% AND ST%
40530 GOTO 40560
40540 PBDAT%=PBDAT% OR ST%
40550 OUT TPPB%,PBDAT%
40560 ST%=NOT(ST%)
40570 RETURN
40600 REM move sample position motor
40610 IF INC=0 THEN RETURN
40620 SPEED=50:SKIP%=SKIP
40625 GOSUB 50000:STM=TIMIN
40630 FOR I=1 TO 200
40640 PLAY "o0l64g"
40650 GOSUB 40500:GOSUB 40800
40660 IF ARRIVED THEN LOCATE 19,44,0:PRINT"er":GOTO 40750
40665 GOSUB 50000:IF TIMIN)STM+FASPDM THEN 40680
40670 NEXT I
40680 SPEED=15:SKIP%=0
40690 FOR I=1 TO SLOSPD%
40700 GOSUB 40500:GOSUB 40800
40710 IF ARRIVED THEN 40750
40720 NEXT I
40730 PBDAT%=PBDAT% AND &H8F:OUT TPPB%,PBDAT%
40750 INC=0:RETURN
40800 PBDAT%=PBDAT% AND &H8F:ARRIVED=0
40810 OUT TPPB%,PBDAT%
40820 IF INC)0 THEN PBDAT%=PBDAT% OR &H10
40830 IF INC(0 THEN PBDAT%=PBDAT% OR &H40
40835 OUT TPPB%,PBDAT%
40840 FOR J=1 TO 50
40850 IF J)=SPEED THEN OUT TPPB%,PBDAT% AND &H8F
40855 IF I(SKIP% THEN 40870
40860 IF (INP(TPPA%) AND 1) THEN ARRIVED=1:PBDAT%=PBDAT% AND &H6F:OUT TPPB%,PBDAT%:RETURN
40870 NEXT J
40880 RETURN
40900 PLAY "o5L2a":LOCATE 20,27,0:IF ERR=27 OR ERR=24 THEN PRINT "   printer is off !  " ELSE PRINT "error #";ERR;"in line";ERL
40910 EXPROC=0:COMM$="":RESUME 1000
50000 REM time convert
50010 T$=TIME$
50020 TIMIN=60*VAL(MID$(T$,1,2))+VAL(MID$(T$,4,2))+VAL(MID$(T$,7,2))/60+CLKROL
50030 IF TIMIN(PTIMIN THEN CLKROL=PTIMIN
50040 PTIMIN=TIMIN
50050 EXPTM=TIMIN-STRTM
50060 RETURN
55000 REM wind down
55003 EXRPT = EXRPT - 1:IF EXRPT ) 0 THEN GOTO 910
55005 IF DONE THEN 55100
55010 FOR K=1 TO 5:INC=-1:GOSUB 40600:NEXT :INC=1:GOSUB 40600
55015 SAMPOS%=1:LOCATE 19,44,0:PRINT USING "##";SAMPOS%
55020 RPMSET=0:GOSUB 1170
55030 OTSET1=TSET1:TSET1=0:GOSUB 1200
```

```
55040 OTSET2=TSET2:TSET2=0:GOSUB 1250
55050 OGHWSET=GHWSET:GHWSET=0:GOSUB 1450
55060 DONE=1
55100 IF TC2 ) 500 THEN 1000
55120 IF DONE=2 THEN 1000
55130 DONE=2
55140 OGASET1=GASET1:GASET1=0:GOSUB 1300
55150 OGASET2=GASET2:GASET2=0:GOSUB 1350
55160 OGASET3=GASET3:GASET3=0:GOSUB 1400
55170 PLAY "cbcbcbcbcbcbcbcbcbcbcbc"
60000 REM PRINT REPORT
60004 LPRINT FF$;LF$
60005 LPRINT " OPERATOR: ";OPNAM$;"                                                    ";DATE$
60007 PRINT LF$;LF$:REM 2 lines
60010 LPRINT TAB(10);CESHEAD$(1)
60020 LPRINT TAB(3);CESHEAD$(2)
60030 LPRINT"":LPRINT TAB(30);"EXPERIMENT REPORT"
60050 LPRINT LF$;LF$;LF$
60060 LPRINT "       TEST GAS COMPOSITION:";
60065 LPRINT "                    TEST CONDITIONS:"
60070 LPRINT""
60080 LPRINT USING "         nitrogen.... ###.# %";GCOMP(1);
60085 LPRINT USING "         main fornace temperature: #### C";OTSET1
60090 LPRINT USING "           oxygen.... ###.# %";GCOMP(2);
60095 LPRINT USING "     pre-heat furnace temperature: #### C";OTSET2
60100 LPRINT USING "  carbon dioxide.... ###.# %";GCOMP(3);
60105 LPRINT USING "        input power to gas heater: #### WATTS";OGHWSET
60110 LPRINT USING "  carbon monoxide.... ###.# %";GCOMP(4);
60115 LPRINT USING "                    main gas flow: ##.# lpm";OGASET1
60120 LPRINT USING "      water vapor.... ###.# %";GCOMP(5);
60125 LPRINT USING "         particle feeder gas flow: ##.# lpm";OGASET2
60130 LPRINT USING "   sulfur dioxide.... ###.# %";GCOMP(6);
60135 LPRINT USING "                     SO2 gas flow: .### lpm";OGASET3
60190 LPRINT""
60200 LPRINT"            ERODANT TYPE: ";SDISCR$(9)
60210 LPRINT""
60215 LPRINT"    ERODE TIME FOR SAMPLE: ";LF$
60220 FOR SII = 1 TO 4
60230 LPRINT"                          #";SII;TMPERSM(SII);" minutes"
60240 NEXT SII
60270 LPRINT"        POWDER FEED AUGER RPM:"
60272 LPRINT"          minimum during run:";PFRPMN
60273 LPRINT"          maximum during run:";PFRPMX;LF$
60275 LPRINT "":LPRINT "      ESTIMATED GAS TEMPS:";LF$
60280 LPRINT USING "           from gas heater: #### C";OTGAS
60285 LPRINT USING "  after particle entrainment: #### C";OTGAS
60290 LPRINT LF$
60295 LPRINT USING "      ESTIMATED GAS VELOCITY: ###.# m/s";OHGASV
60296 LPRINT ""
60300 LPRINT USING "  MEASURED PARTICLE VELOCITY: ###.# m/s";MPV
60304 LPRINT LF$
60305 LPRINT"  SAMPLE DISCRIPTIONS:
60310 LPRINT""
60315 FOR SN=1 TO 4
60320 LPRINT USING "sample no. ## : ";SN;:LPRINT SDISCR$(SN)
60325 NEXT SN
60328 LPRINT LF$;LF$
60330 LPRINT"               GENERAL NOTES:"
60340 LPRINT"                                ";SDISCR$(10)
60395 LPRINT FF$:EXPROC=0:GOTO 1000
60400 REM data verification header
```

```
60410 LPRINT FF$:REM form feed
60415 LPRINT " OPERATOR: ";OPNAM$;"                                        DATE: ";DATE$
60420 LPRINT LF$;LF$:REM 2 lines
60430 LPRINT TAB(10);CESHEAD$(1)
60440 LPRINT TAB(3);CESHEAD$(2)
60450 LPRINT"":LPRINT TAB(22);"EXPERIMENTAL CONDITION VERIFICATION"
60460 LPRINT"":LPRINT "          Temperatures deg C              Gas flows lpm          auger"
60470 LPRINT"time     main  pre-heat  sample block   main  powder feed   SO2       rpm"
60480 RETURN
60500 LPRINT T$;
60510 LPRINT USING " ####    ";TC1;TC2;TC3;
60515 LPRINT "  ";
60520 LPRINT USING "   ##.#   ";GASFLO1;GASFLO2;
60530 LPRINT USING "  .###   ";GASFLO3;
60540 LPRINT USING "    ####";RPM2
60550 RETURN
```